

COOPERATIVE SNOW INVESTIGATIONS

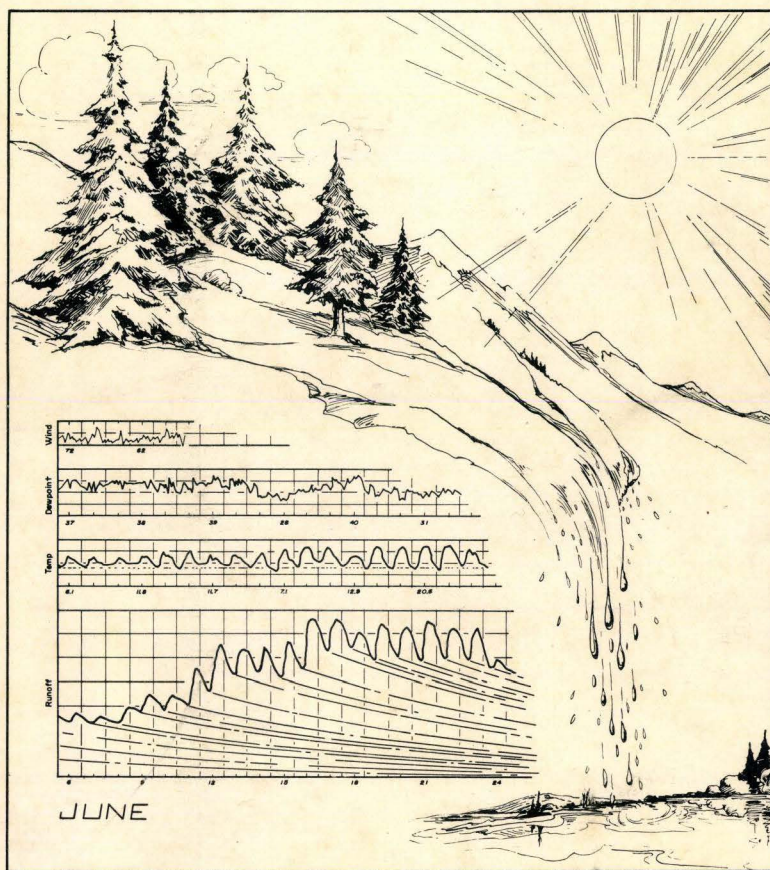
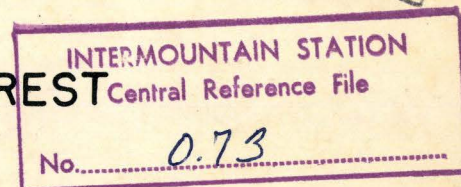
DEPARTMENT OF AGRICULTURE
FOREST SERVICE
ROCKY MOUNTAIN FOREST AND
RANGE EXPERIMENT STATION

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
PROJECT PLANNING DIVISION
HYDROLOGY BRANCH



PROGRESS IN SNOWMELT INVESTIGATIONS

AT THE
FRASER EXPERIMENTAL FOREST
COLORADO



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REPORT NO. 2 THE 1949 SNOWMELT SEASON

JUNE 1951

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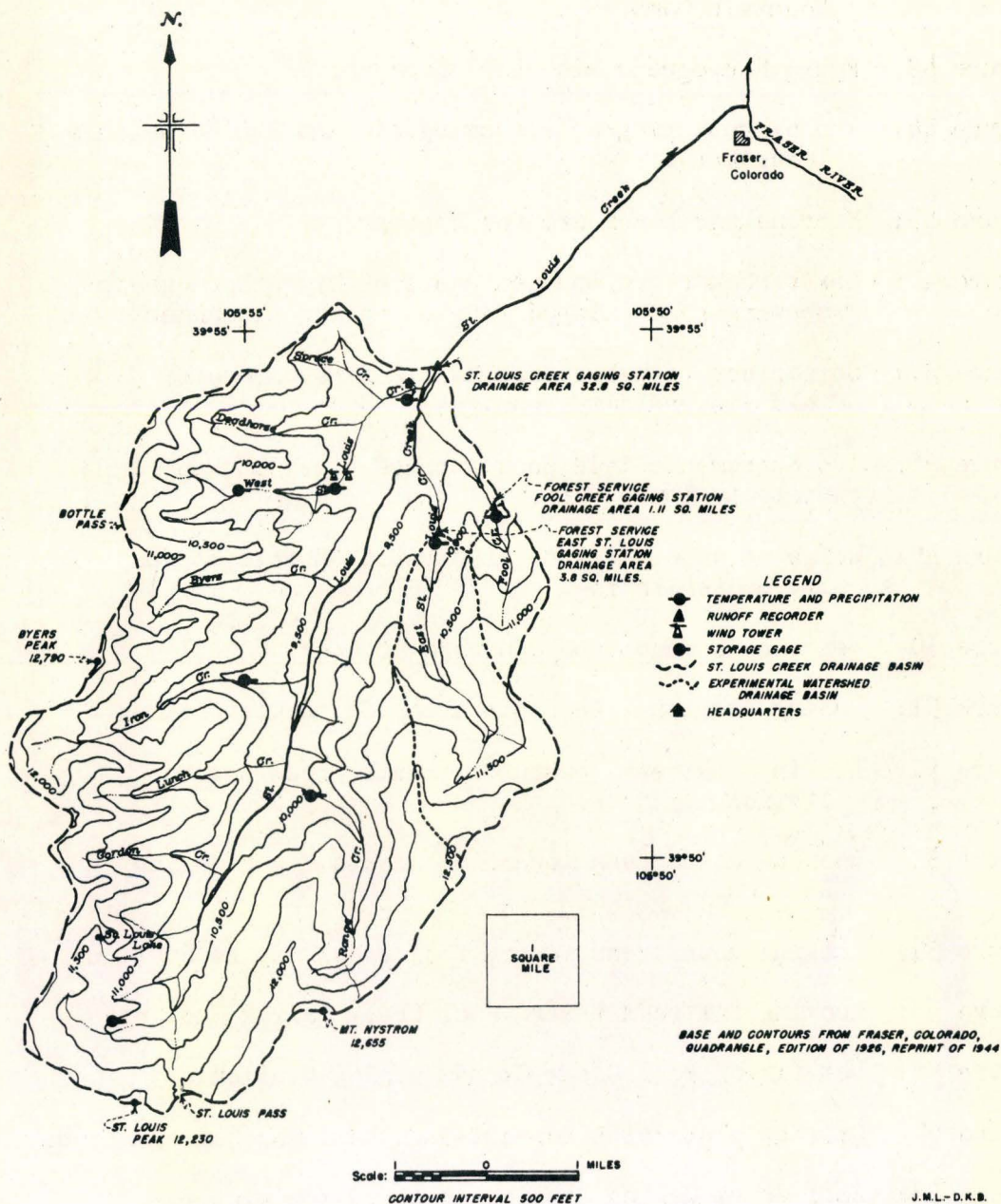
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ST. LOUIS CREEK DRAINAGE AREA
FRASER EXPERIMENTAL FOREST, COLORADO



REPORT NO. 2

PROGRESS IN SNOWMELT INVESTIGATIONS AT THE FRASER EXPERIMENTAL FOREST

THE 1949 SNOWMELT SEASON

A. INTRODUCTION.

This is the second progress report on cooperative snow investigations being conducted by the Bureau of Reclamation and the Forest Service at the Fraser Experimental Forest near Fraser, Colorado, under the general direction of Mr. J. R. Riter, Chief, Hydrology Branch, Project Planning Division, Bureau of Reclamation, United States Department of the Interior, Denver, Colorado; and Dr. W. G. McGinnies, Director, Rocky Mountain Forest and Range Experiment Station, Forest Service, United States Department of Agriculture, Fort Collins, Colorado. A detailed description of the Fraser Experimental Forest is given in REPORT NO. 1, THE 1948 SNOWMELT SEASON (8). ^{1/} A map of the St. Louis Creek drainage basin is shown on the frontispiece. Certain forest influences investigations which the Forest Service has been conducting in the Fraser Experimental Forest are described by Wilm and Dunford (31). The Bureau of Reclamation's interest in this cooperative investigation stemmed from the desire for improving the accuracy of both seasonal water yield and rate-of-run-off forecasts for use in the planning and operation of Reclamation projects; and from the need for more precise information about rates of run-off from snowmelt for use in flood design studies and computations, as set forth in Report No. 1 (8).

This progress report covers the five subprojects reported in Report No. 1, as viewed in the light of newer methods of analysis applied to the data from both the 1948 and 1949 snowmelt seasons. In addition, a new Section G on instrumentation is presented in this report. Computations and analyses completed for the 1949 season are summarized; however, many charts and tables, including voluminous basic collected data on air temperature, relative humidity, wind travel, solar radiation, and stream flow, are not included in this report. Specific portions of such data are available on request.

Studies completed to date do not by any means exhaust the analytical possibilities. Investigations are being continued and the results will be presented in a forthcoming report which will include observations made during the 1950 season.

^{1/} Numbers in parentheses refer to "References," Section I, p. '78.

B. OBSERVATIONS OF THE PERFORMANCE OF SACRAMENTO-TYPE SHIELDED

PRECIPITATION STORAGE GAGES.

The performance of the Weather Bureau Design, Sacramento-type shielded seasonal-storage precipitation gages during the 1949 season was included in Report No. 1 together with results for the 1947 and 1948 seasons. Also, in Report No. 1 is a detailed discussion with several photographs of the storage gage installations and their performance in the Fraser Experimental Forest.

The above results summarized in Table 1 indicate that, under conditions of snowfall and temperature trends following snowfall prevailing in the Colorado Rocky Mountains, such gages do not yield a reliable measurement of a total winter season's precipitation.

C. INVESTIGATION OF METHODS OF INTERPRETING THE COMMONLY AVAILABLE

DAILY MAXIMUM AND MINIMUM TEMPERATURES IN TERMS OF DEGREE-DAYS ABOVE 32°F.

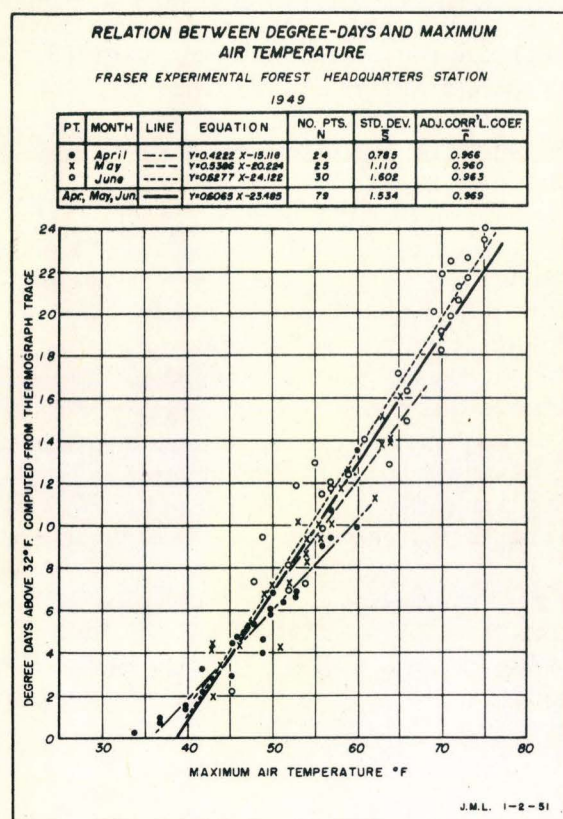


FIGURE 1. Relation between degree-days and maximum air temperature.

The purpose of this part of the investigation is to determine a more accurate evaluation of heat from air temperature in connection with snowmelt studies. The study was carried out in a manner similar to that described in Report No. 1.

Additional charts and table prepared in this study for the 1949 data are presented in Figures 1 to 4 inclusive and Table 2. The charts show linear relationships between degree-days above 32°F as computed from hourly thermograph records and (a) the maximum temperature, (b) the average of the maximum and minimum temperature, and (c) the average of the maximum and effective minimum temperature. For (c) the effective minimum temperature is defined as the actual minimum if it is equal to or above 32°F, but if the actual minimum is below 32°F, the effective minimum is considered to be 32°F.

TABLE 1. Summary of seasonal storage precipitation gages, 1947-1949.

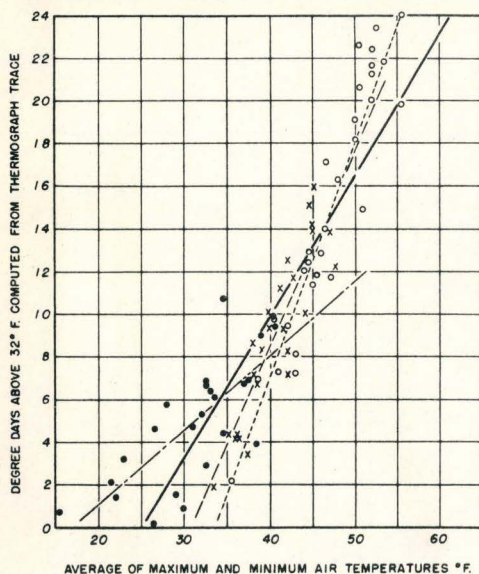
SUMMARY OF SEASONAL STORAGE PRECIPITATION GAGES, 1947 TO 1949													
Station Elevation (ft) Capacity (inch) Condition		East St. Louis Creek 9,520 100 Shielded		Iron Creek 9,580 100 Shielded		Range Creek 9,360 100 Shielded		St. Louis Pass 10,330 200 Unshielded		West St. Louis Creek 9,840 100 Shielded		West St. Louis Creek 9,840 100 Unshielded	
		Date or Period	Water Equivalent (inch)	Date or Period	Water Equivalent (inch)	Date or Period	Water Equivalent (inch)	Date or Period	Water Equivalent (inch)	Date or Period	Water Equivalent (inch)	Date or Period	Water Equivalent (inch)
1947	April 1	Gage Increment Snow Survey	11/17/46-4/1/47 4/1/47	9.25 13.80	11/16/46-4/1/47 4/1/47	11.25 11.75	11/16/46-4/1/47 4/1/47	9.25 14.15	10/25/46-4/3/47 4/3/47	21.00 23.11	11/17/46-4/2/47 4/2/47	10.40 28.77	- - - - - -
	May 1	Gage Increment Snow Survey	4/1/47-5/2/47 5/2/47	3.50 14.92	4/1/47-4/29/47 4/29/47	4.00 12.92	4/1/47-4/29/47 4/29/47	3.50 15.42	4/3/47-4/30/47 4/30/47	5.80 23.32	4/2/47-4/29/47 4/29/47	4.15 23.92	- - - - - -
1948	April 1	Gage Increment Snow Survey	9/27/47-4/2/48 4/2/48	12.50 14.35	9/26/47-3/31/48 3/31/48	13.50 11.25	9/26/47-3/31/48 3/31/48	12.00 13.40	9/26/47-4/1/48 4/1/48	10.50 18.95	9/25/47-4/2/48 4/2/48	18.00 20.25	- - - - - -
	May 1	Gage Increment Snow Survey	4/2/48-4/28/48 4/28/48	3.00 10.65	3/31/48-5/4/48 5/4/48	4.00 6.10	3/31/48-5/4/48 5/4/48	4.50 10.15	4/1/48-5/4/48 5/4/48	9.00 18.55	4/2/48-4/29/48 4/29/48	5.50 16.96	
1949	April 1	Gage Increment Snow Survey	9/22/48-4/8/49 4/8/49	11.7 14.0	10/2/48-4/12/49 4/12/49	13.3 10.7	10/1/48-4/12/49 4/12/49	10.8 11.6	10/1/48-4/12/49 4/12/49	17.3 20.0	9/28/48-4/7/49 4/7/49	18.1 19.1	9/28/48-4/7/49 4/7/49
	May 1	Gage Increment Snow Survey	4/8/49-5/2/49 5/2/49	1.8 11.3	4/12/49-5/3/49 5/3/49	2.0 0.0	4/12/49-5/3/49 5/3/49	1.8 8.1	4/12/49-5/3/49 5/3/49	2.8 18.5	4/7/49-4/29/49 4/29/49	2.3 14.7	4/7/49-4/29/49 4/29/49

RELATION BETWEEN DEGREE-DAYS AND AVERAGE OF MAXIMUM AND MINIMUM AIR TEMPERATURES

FRASER EXPERIMENTAL FOREST HEADQUARTERS STATION

1949

PT.	MONTH	LINE	EQUATION	NO. PTS.	STD. DEV.	ADJ. CORR'L. COEF.
				N	S	F
•	April	---	$Y=0.3512X-5.981$	24	2.05	0.734
x	May	---	$Y=0.3288X-28.694$	25	1.79	0.693
o	June	---	$Y=1.1036X-37.074$	30	2.05	0.939
	Apr., May, Jun.	---	$Y=0.6633X-16.617$	79	2.81	0.892



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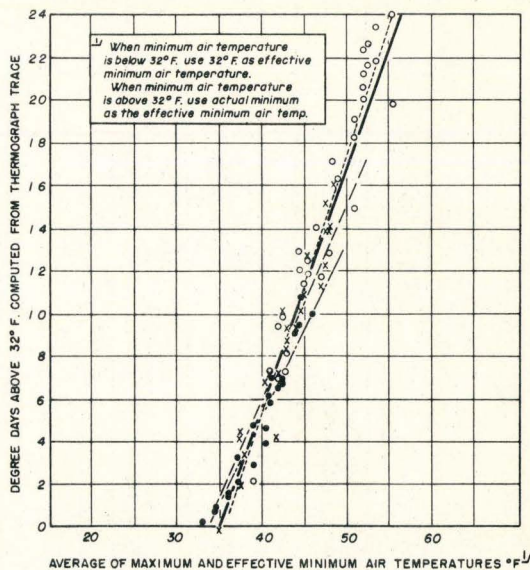
FIGURE 2. Relation between degree-days and average of maximum and minimum air temperatures.

RELATION BETWEEN DEGREE-DAYS AND AVERAGE OF MAXIMUM AND EFFECTIVE MINIMUM AIR TEMPERATURES ¹

FRASER EXPERIMENTAL FOREST HEADQUARTERS STATION

1949

PT.	MONTH	LINE	EQUATION	NO. PTS.	STD. DEV.	ADJ. CORR'L. COEF.
				N	S	F
•	April	---	$Y=0.8278X-27.96$	24	1.983	0.957
x	May	---	$Y=0.9117X-30.54$	25	1.727	0.901
o	June	---	$Y=1.2145X-43.23$	30	1.720	0.957
	Apr., May, Jun.	---	$Y=1.1265X-39.540$	79	1.704	0.962



P. R. 2-2-51

FIGURE 3. Relation between degree-days and average of maximum and effective minimum air temperatures.

SUMMARY OF DEGREE-DAY CORRELATIONS

Degree-days (Y) as Computed From Hourly Values of Hygrothermograph Records in Relation to (X) Daily Max. Temp, Avg. of Max. & Min. Temp, or Avg. of Max. & Effective Min. Temp.
Fraser Experimental Forest Headquarters Station

Year	Month	Comparison with maximum temperature			Comparison with average of maximum & minimum temperature			Comparison with average of maximum & effective minimum temperature		
		Equation	F	S	Equation	F	S	Equation	F	S
1948	April	$Y=0.444X-15.9$	0.981	0.73	$Y=0.585X-13.4$	0.938	1.29	$Y=0.888X-30.1$	0.981	0.73
1949	April	$Y=0.422X-15.1$	0.966	0.78	$Y=0.351X-6.0$	0.734	2.05	$Y=0.828X-28.0$	0.957	1.98
1948	May	$Y=0.532X-19.5$	0.982	0.94	$Y=0.742X-18.9$	0.962	1.36	$Y=1.064X-36.5$	0.982	0.94
1949	May	$Y=0.539X-20.2$	0.960	1.11	$Y=0.929X-28.7$	0.893	1.79	$Y=0.912X-30.5$	0.901	1.73
1948	June	$Y=0.545X-19.2$	0.927	1.72	$Y=1.218X-42.4$	0.887	2.12	$Y=1.188X-42.1$	0.948	1.46
1949	June	$Y=0.628X-24.1$	0.963	1.60	$Y=1.104X-37.1$	0.939	2.05	$Y=1.214X-43.2$	0.957	1.72
1948	April+ May+June	$Y=0.569X-21.5$	0.966	1.52	$Y=0.739X-19.0$	0.939	2.02	$Y=1.134X-39.7$	0.975	1.30
1949	April+ May+June	$Y=0.606X-23.5$	0.969	1.53	$Y=0.663X-16.6$	0.892	2.81	$Y=1.126X-39.5$	0.962	1.70

TABLE 2. Summary of degree-day correlations.

Computations of lines by the least squares method were made of the dispersions of temperature data for April, May, and June of 1949 in the three different categories, (a), (b), and (c) above. The computed lines for each month and line for the three-month total in each case are shown in Figures 1, 2, and 3. A comparison of these results with the equations derived for the 1948 data is shown in Table 2. In general the highest correlation coefficients were obtained between degree-days as computed from hourly values from a thermograph trace and the maximum temperature.

A method suggested by W. R. Slater (24), Region 3, Bureau of Reclamation, Boulder City, Nevada, for estimating degree-days by using maximum temperature and daily range of temperature was tried on the 1949 data from the Fraser Forest Headquarters Station. The scatter diagram and curves drawn in by eye for the various 10° intervals of daily range in temperature are shown in Figure 4, using data for May and June 1949.

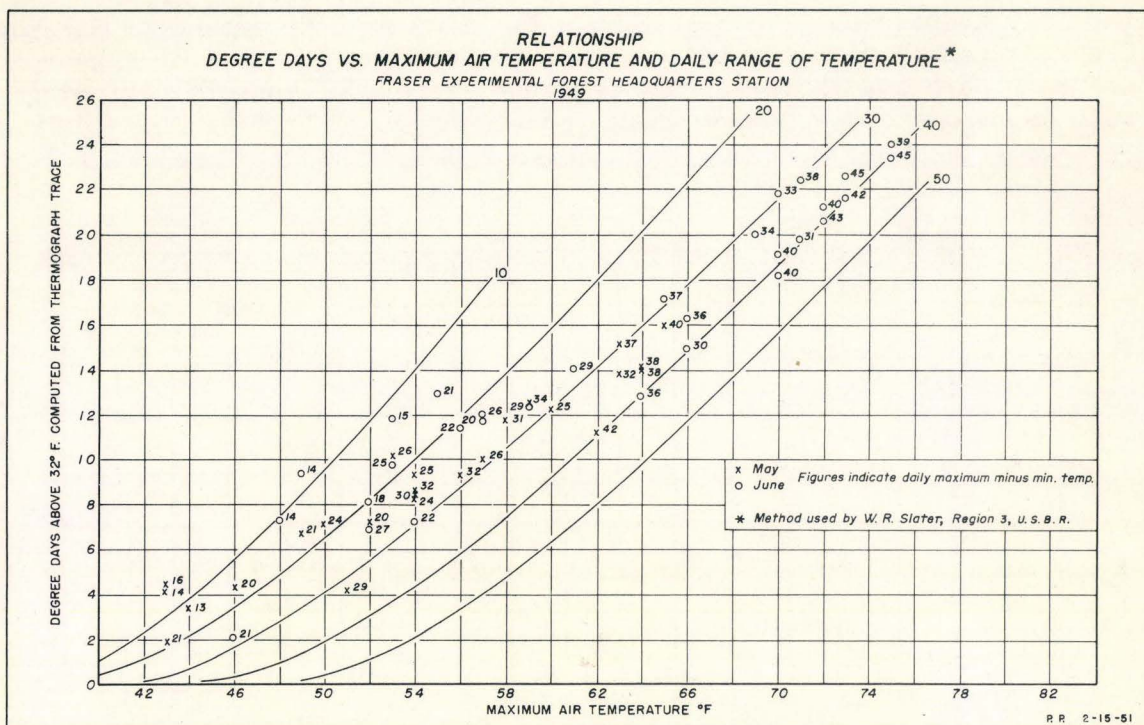


FIGURE 4. Relation between degree-days and maximum air temperature and daily range of temperature.

D. ANALYSIS OF RATES OF SNOWMELT.

St. Louis Creek

The periods of record chosen for analysis of run-off in St. Louis Creek are: May 14-16, May 19-24, and May 27-June 5, 1948; and May 23-27, June 1-10, and June 15-25, 1949. Days other than those enumerated above were not used as all data needed were not available for certain analyses. For example, in Figure 9 it will be noted that records of wind at the 47.4-foot level in the open are not available for May 29, 30, 31 and June 11, 12, 13, 14, 1949. Thus, even though run-off records are complete, and data are available on solar radiation, air temperature, degree-days above 32°F, relative humidity, and dewpoint, it was not possible to use these days in multiple correlation analyses including wind as one of the variables. However, all available run-off records were used in the analyses shown in Figures 12, 13, 14, 15, and 16, and described in Section F, "Synthesis of the Snowmelt Hydrograph." The periods of record used in the analysis of rates of snowmelt include the major rise to the seasonal peak and also a few days after the peak of the 1949 hydrograph, shown in Figure 5. Similar hydrographs of St. Louis Creek, together with precipitation as observed at the town of Fraser, Colorado, are available for the period of record of run-off beginning with 1935.

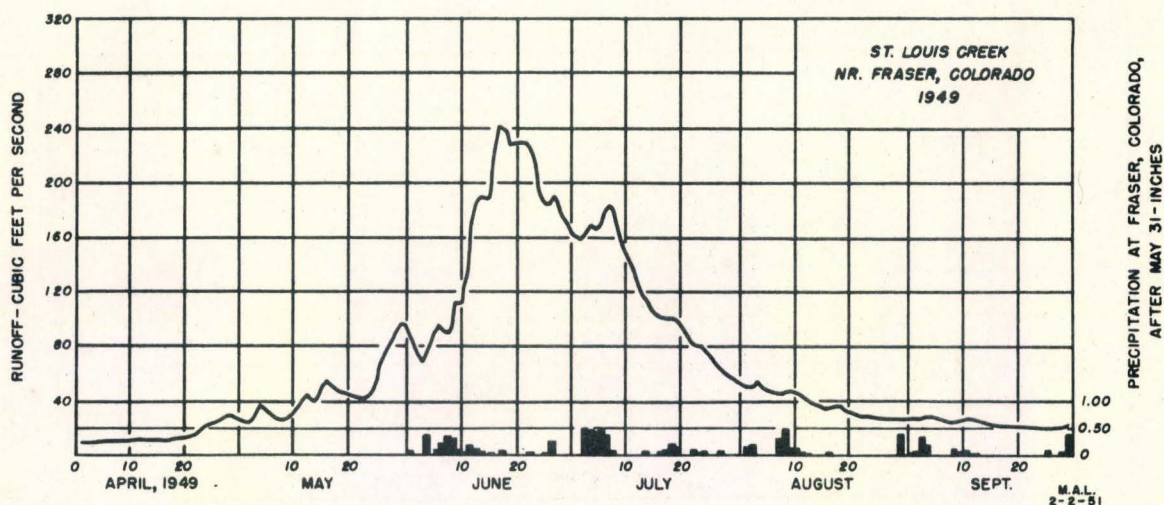


FIGURE 5. Hydrograph of St. Louis Creek, 1949.

Before correlative analyses between heat and snowmelt were attempted, it was necessary to segregate from the hydrograph the contribution of one day's snowmelt. This analysis of the snowmelt hydrograph is based upon field experience in observing watershed run-off from snowmelt. In forested watersheds there is, in effect, no watershed-wide overland flow from snowmelt. Practically all of the snowmelt run-off

enters stream channels as subsurface or ground-water flow, usually as a combination of both. The hydrograph recession of the end of the snowmelt season should apply to each day of snowmelt contribution to the total flow, as the run-off is the summation of the individual day's contributions of discharge of water through a porous medium, rather than the summation of overland hydraulic flows.

Accordingly, yesterday's flow in cfs of St. Louis Creek was plotted against today's flow using only the falling stages of days uninfluenced by rainfall for the 1947 and 1948 snowmelt seasons to determine a recession factor. The daily recession factors as computed from that plotting were found to be 0.933 for stages above about 30 cfs and 0.981 for stages below about 30 cfs. A chart showing this relationship is presented on page 41 of Report No. 1. These recession values were found to fit the hydrographs of St. Louis Creek for the period 1935 to 1948, inclusive. Figure 6 shows the recession relationship supplemented by the addition of data from the 1949 snowmelt season. The daily recession values as based on 1947 and 1948 data also fit the 1949 data.

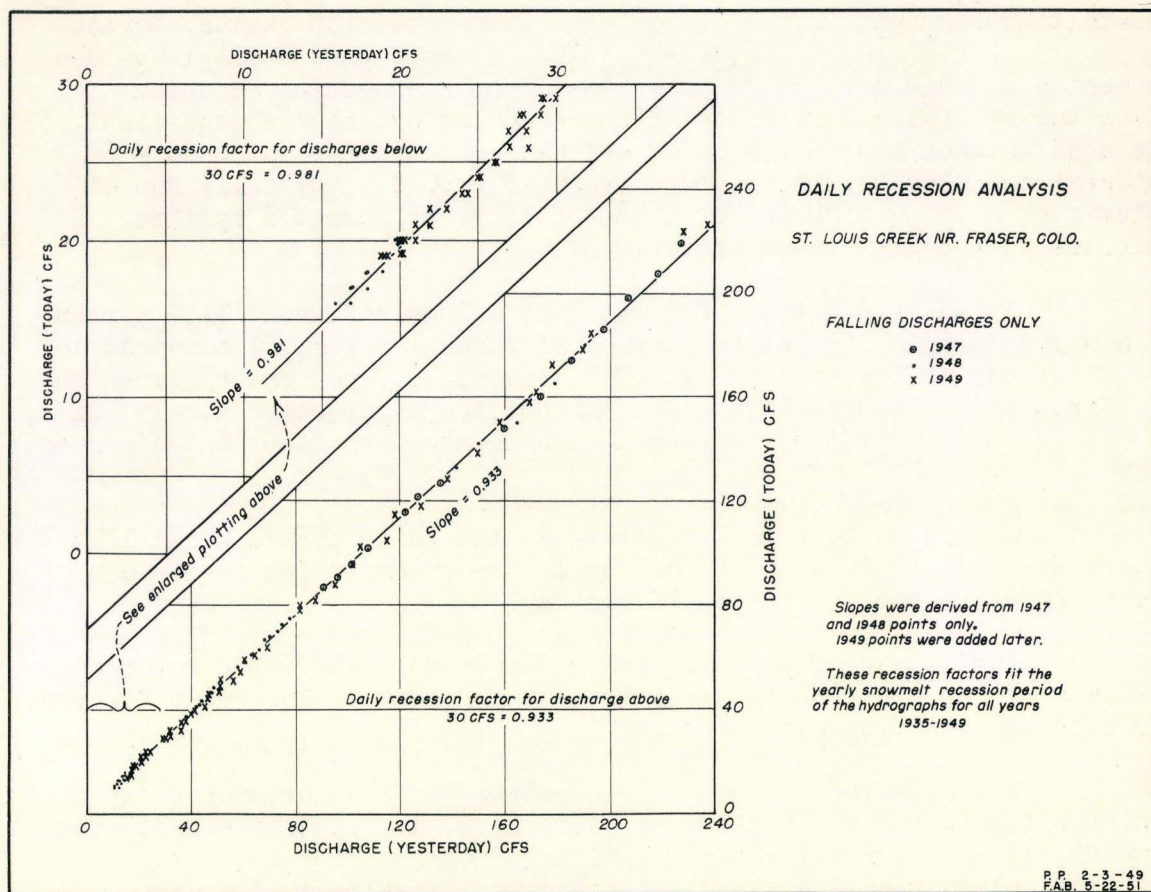
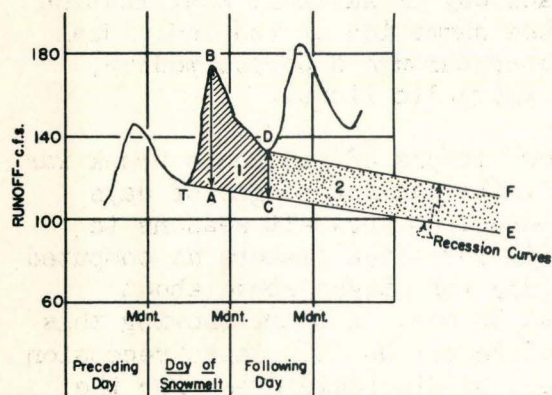


FIGURE 6. St. Louis Creek recession, 1947, 48, and 49.

METHOD OF COMPUTATION OF SNOWMELT HYDROGRAPH



Area 1 = Volume of a day's snowmelt appearing in the first 24-hour period. (First day volume)
 Area 2 = Volume of a day's snowmelt in recession flow.
 Total snowmelt for the day = Area 1 + Area 2.

FIGURE 7. Method of computation of snowmelt hydrograph.

recession above a horizontal base line in an exponential equation. Since the recession curves can be expressed as exponential equations, the area between two recession curves was computed by a procedure of integral calculus developed and shown in Figure 8. The daily run-off volumes of St. Louis Creek for 1948 and 1949, as computed by this calculus method are listed in Table 3.

It was found that, for the 1948 snowmelt season, 11.2 percent of a day's total contribution to run-off (Area 1 + Area 2) appeared on the first day as Area 1; for the 1949 season, 11.7 percent appeared on the first day. The remaining 88.8 and 88.3 percent, respectively, of the day's contribution to the snowmelt hydrograph constitute the recession flows.

As may be observed in Figure 9, the daily peak of Area 1 occurs at about 8-10 p.m. on the day of the snowmelt and the trough occurs at about noon of the following day.

A time lag of approximately 6 hours was determined between the peak of the air temperature curve and the peak of the run-off curve for each day for St. Louis Creek.

Figure 9 and Table 3 show negative total volumes of a day's contribution to run-off for May 31, June 1, 2, 18, and, in effect, for June 23, 1949. Figure 9 shows graphically for June 18, 1949, the negative volume resulting from the calculus computation of a day's total contribution when the trough of one day falls below the recession line of the preceding day.

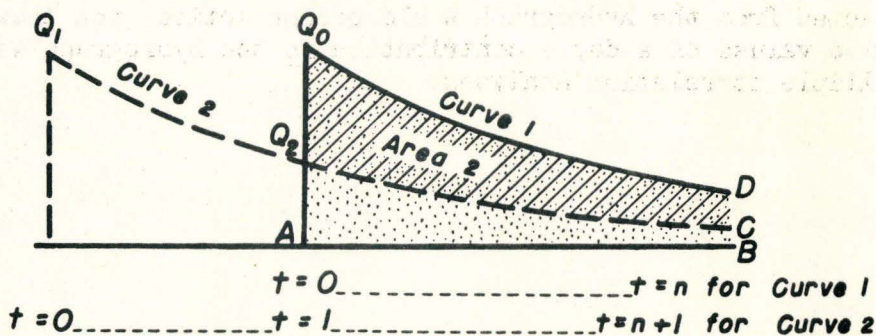
A day's contribution to the snowmelt hydrograph was considered as the sum of the Areas 1 and 2 as shown on Figure 7. Standard recession curves developed from the recession factors were drawn from the troughs of the hydrograph as shown on Figure 9. In this series of analyses, a winter flow of about 8 cfs was considered as the base above which contributions of individual day's snowmelt could be segregated. The individual day's snowmelt contributions were derived by planimetering Area 1 under the day's peak on the hydrograph and by computing by calculus Area 2, the wedge between the two recession curves. Barnes (4) expressed a single-valued

No definite explanation can be offered at this time for this appearance of negative volumes. It may be due to some unrecognized variability in the value of the recession coefficient. It could also be caused by sudden and short duration freezing of melt water in transit in subsurface or other run-off courses. Such a sudden freezing would in effect abstract from the hydrograph certain portions of a day's total contribution to run-off and produce a retrogression of the hydrograph to the recession line of some preceding day's contribution. As subsurface flow thus temporarily abstracted from the hydrograph would become active upon thawing, the negative values of a day's contribution to the hydrograph were used in multiple correlation analyses.

RECESSION OF HYDROGRAPH

$$Q = Q_0 K_r^t$$

$$R = \int Q dt = \int Q_0 K_r^t dt = Q_0 \frac{K_r^t}{\log_e K_r}$$



$$\text{Area } Q_0 ABD: Q_0 \frac{K_r^t}{\log_e K_r} \Big|_0^n = Q_0 \left[\frac{K_r^n}{\log_e K_r} - \frac{K_r^0}{\log_e K_r} \right] = Q_0 \left[\frac{K_r^n - 1}{\log_e K_r} \right]$$

$$\text{Area } Q_1 ABC: Q_1 \frac{K_r^t}{\log_e K_r} \Big|_1^{n+1} = Q_1 \left[\frac{K_r^{n+1}}{\log_e K_r} - \frac{K_r^1}{\log_e K_r} \right] = K_r Q_1 \left[\frac{K_r^n - 1}{\log_e K_r} \right]$$

$$\text{Difference: Area 2} = Q_0 \left[\frac{K_r^n - 1}{\log_e K_r} \right] - K_r Q_1 \left[\frac{K_r^n - 1}{\log_e K_r} \right] =$$

$$\frac{Q_0 (K_r^n - 1) - K_r Q_1 (K_r^n - 1)}{\log_e K_r} \quad \text{or} \quad \frac{(Q_0 - K_r Q_1) (K_r^n - 1)}{\log_e K_r}$$

$$\log_e K_r = 2.30259 \log_{10} K_r.$$

Q = Flow in cfs at time t .

t = time in days.

K_r = Runoff recession constant.

Q_0 = Flow in cfs at time $t=0$. R = Area under recession curve in cfs days.

P.M.F. 3-11-49
REV. 5-28-51

FIGURE 8 Hydrograph Recession Equations

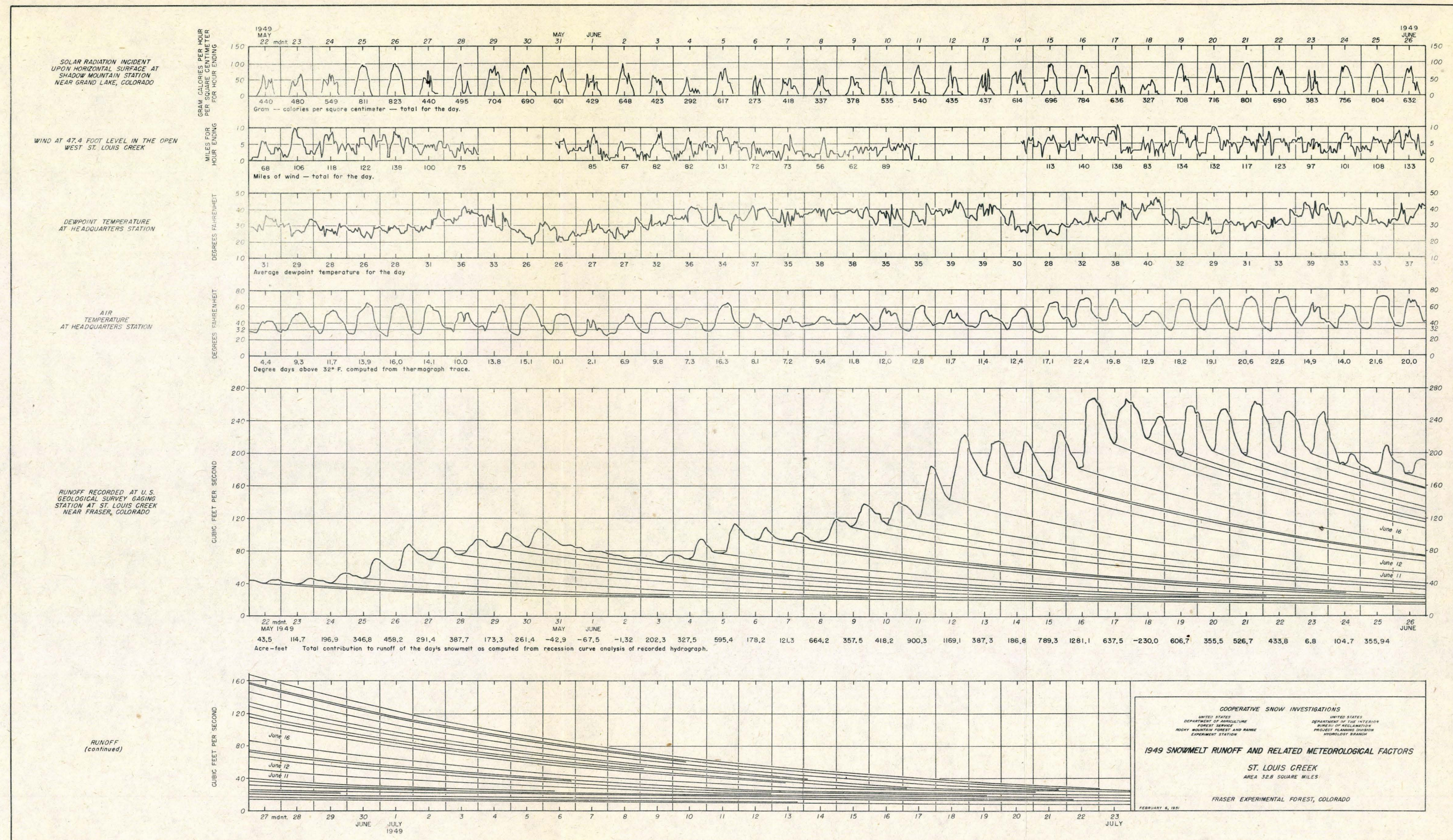


FIGURE 9
11

RUN-OFF VOLUMES

St. Louis Creek

1948

1949

Date 1948	Trough 1/ cfs	Peak 2/ cfs	Total first day volume 3/ acre-ft	Net first day volume above recession 4/ acre-feet	Total run- off between recession lines 5/ acre-feet	Date 1949	Trough 1/ cfs	Peak 2/ cfs	Total first day volume 3/ acre-ft	Net first day volume above recession 4/ acre-feet	Total run- off between recession lines 5/ acre-feet
May 13	15	31	67	29	758	May 19	45	51	96	10	104
14	25	52	83	34	588	20	46	46	88	0	2
15	36	66	109	37	325	21	43	45	85	2	0
16	46	80	126	42	404	22	40	44	82	5	44
17	58	105	180	60	529	23	39	45	84	10	115
18	72	102	158	35	479	24	41	52	95	17	197
19	86	126	229	52	487	25	46	70	119	31	347
20	96	155	251	67	686	26	56	87	148	40	458
21	113	165	281	64	559	27	69	84	154	22	291
22	124	180	300	63	392	28	75	94	171	27	388
23	128	168	301	46	284	29	84	102	190	22	173
24	128	142	254	19	186	30	84	107	200	32	261
25	126	168	273	42	312	31	87	87	153	-1	-43
26	128	128	259	4	-51	June 1	80	80	153	0	-67
27	117	155	280	47	559	2	72	74	141	3	-1
28	128	165	309	44	292	3	67	75	142	14	202
29	128	140	232	16	218	4	70	94	164	30	327
30	128	172	320	64	627	5	77	113	195	47	595
31	140	180	320	63	508	6	93	109	194	16	178
June 1	148	191	348	65	808	7	93	102	189	11	121
2	165	239	404	88	593	8	91	118	204	36	664
3	172	242	429	85	482	9	109	138	268	42	357
4	175	233	413	64	259	10	113	140	246	39	418
5	170	230	376	64	361	11	120	184	310	80	900
6	170					12	142	223	382	109	1,169
						13	172	214	404	61	387
						14	172	214	365	49	187
						15	166	226	395	77	789
						16	181	265	473	126	1,281
						17	211	265	487	83	637
						18	217	244	446	30	-230
						19	193	256	457	87	607
						20	199	253	454	72	356
						21	196	262	460	84	527
						22	199	250	450	68	434
						23	199	250	433	52	7
						24	184	196	367	14	105
						25	175	208	372	36	356
						26	175				

Footnote numbers in Table 3 refer to points designated on Figure 7:

- 1/ Trough is Point T.
- 2/ Peak is Point B.
- 3/ Total area under hydrograph for the day and above a zero base line.
- 4/ Net first day volume is Area 1.
- 5/ Total run-off volume is Area 1 plus Area 2.

TABLE 3: RUN-OFF VOLUMES, ST. LOUIS CREEK, 1948 AND 1949.

Fool Creek

Figure 10 shows the 1949 hydrograph for Fool Creek, a tributary to St. Louis Creek, with the recession lines drawn in for each day. Time lag as determined from 1948 data was approximately 3 hours and the recession factors for Fool Creek flow (varying from 0.871 for flows of about 14 cfs to 0.963 for flows of about 0.105 cfs) as derived in Report No. 1 were used. The amount of run-off attributable to one day's melt was planimetered from the hydrograph on which the recession lines from each day's trough had been drawn. Tabulations of the computed daily run-off volumes for 1948 and 1949 are given in Table 4. As records from the Fool Creek hygrothermograph were not available before June 9, 1949, no attempt was made to correlate the meteorological elements in the Fool Creek area with Fool Creek stream flow.

RUN-OFF VOLUMES

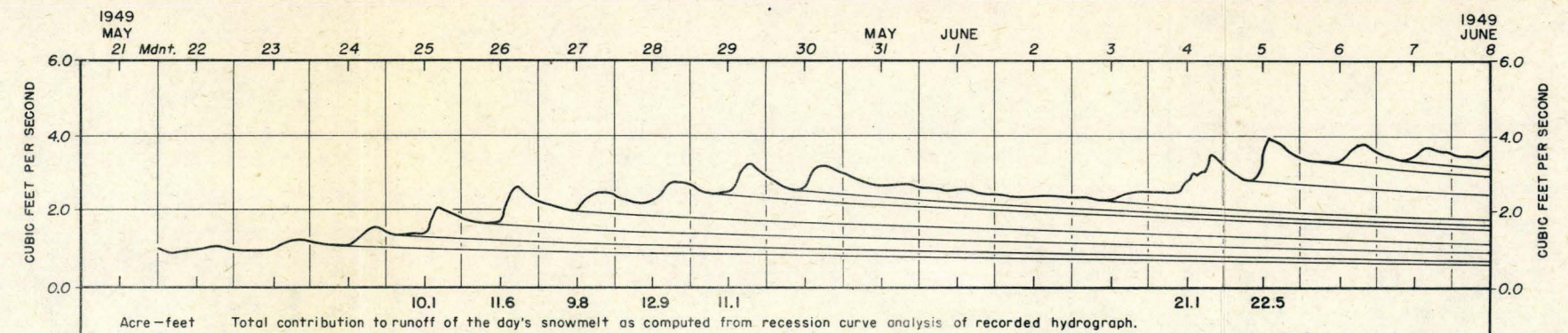
Fool Creek

1948					1949				
Date	Trough cfs	Peak cfs	Net first day volume above recession acre-ft	Total run-off volume between recession lines acre-ft	Date	Trough cfs	Peak cfs	Net first day volume above recession acre-ft	Total run-off volume between recession lines acre-ft
May 16	0.8	1.5	0.8	6.4	May 25	1.3	2.1	0.9	10.1
17	1.2	2.2	1.2	10.4	26	1.6	2.6	1.3	11.6
18	1.6	2.5	1.2	15.0	27	2.0	2.5	0.8	9.8
19	2.0	3.2	1.4	20.1	28	2.2	2.8	1.0	12.9
20	2.5	4.0	1.8	22.3	29	2.5	3.2	0.8	11.1
21	3.0	4.6	2.3	31.3	June 4	2.4	4.0	1.8	21.1
22	3.8	5.4	1.8	19.7	5	2.8	3.9	1.5	22.5
23	4.0	5.1	1.5	21.8	10	5.0	5.6	1.2	19.1
28	5.8	7.1	2.0	15.8	11	5.4	6.5	2.2	34.0
29	6.0	7.1	1.8	20.4	13	7.6	8.9	2.8	26.8
30	6.1	9.1	4.6	44.3	14	8.2	9.4	2.2	15.3
31	7.8	10.1	3.9	22.4	15	8.1	10.6	4.3	40.0
June 1	8.1	10.3	3.6	29.6	16	9.5	13.7	6.4	39.6
2	8.8	12.5	5.5	30.9	17	10.9	14.1	4.8	25.1
3	9.6	13.2	5.0	26.4	19	9.4	12.1	3.4	14.3
4	9.8	12.1	3.4	19.4	20	8.9	11.7	3.2	12.1
5	9.3	11.4	3.0	14.2	21	8.4	10.7	2.9	12.0
6	9.0	11.2	2.9	20.7	22	8.0	9.2	1.7	9.9
7	9.0	10.2	1.7	9.0					
8	8.4	9.2	1.6	11.9					
9	8.0	8.9	1.2	9.1					

TABLE 4. Run-off volumes, Fool Creek, 1948 and 1949.

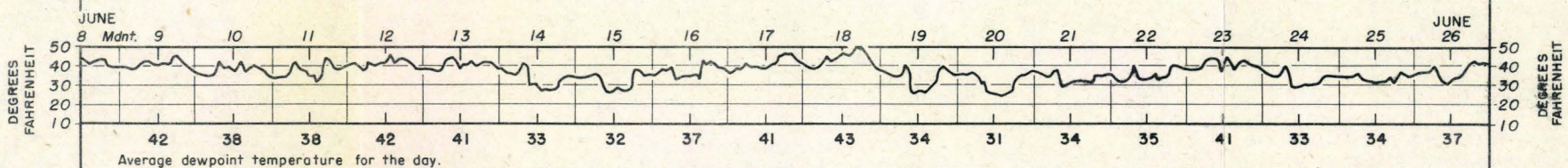
RUNOFF RECORDED AT FOREST SERVICE
GAGING STATION AT FOOL CREEK

RUNOFF RECORDED AT FOREST SERVICE
GAGING STATION AT FOOL CREEK



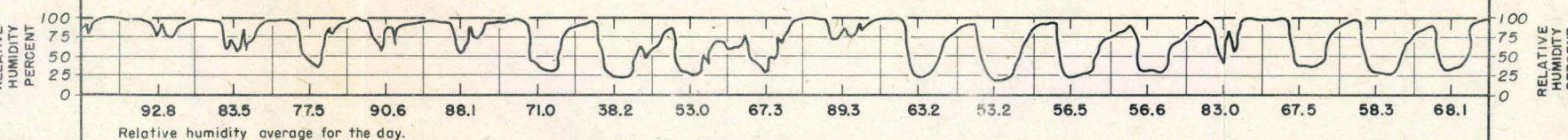
DEWPOINT TEMP. AT FOOL CREEK STATION

DEWPOINT TEMP. AT FOOL CREEK STATION



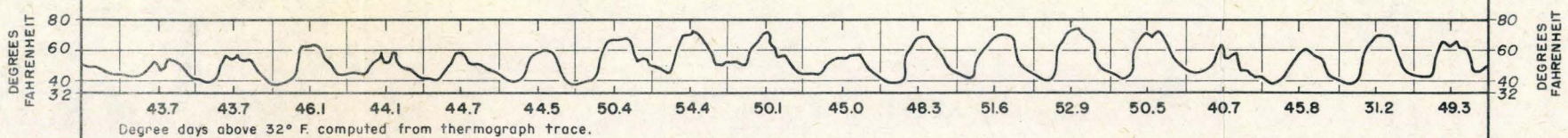
RELATIVE HUMIDITY AT FOOL CREEK STATION

RELATIVE HUMIDITY AT FOOL CREEK STATION



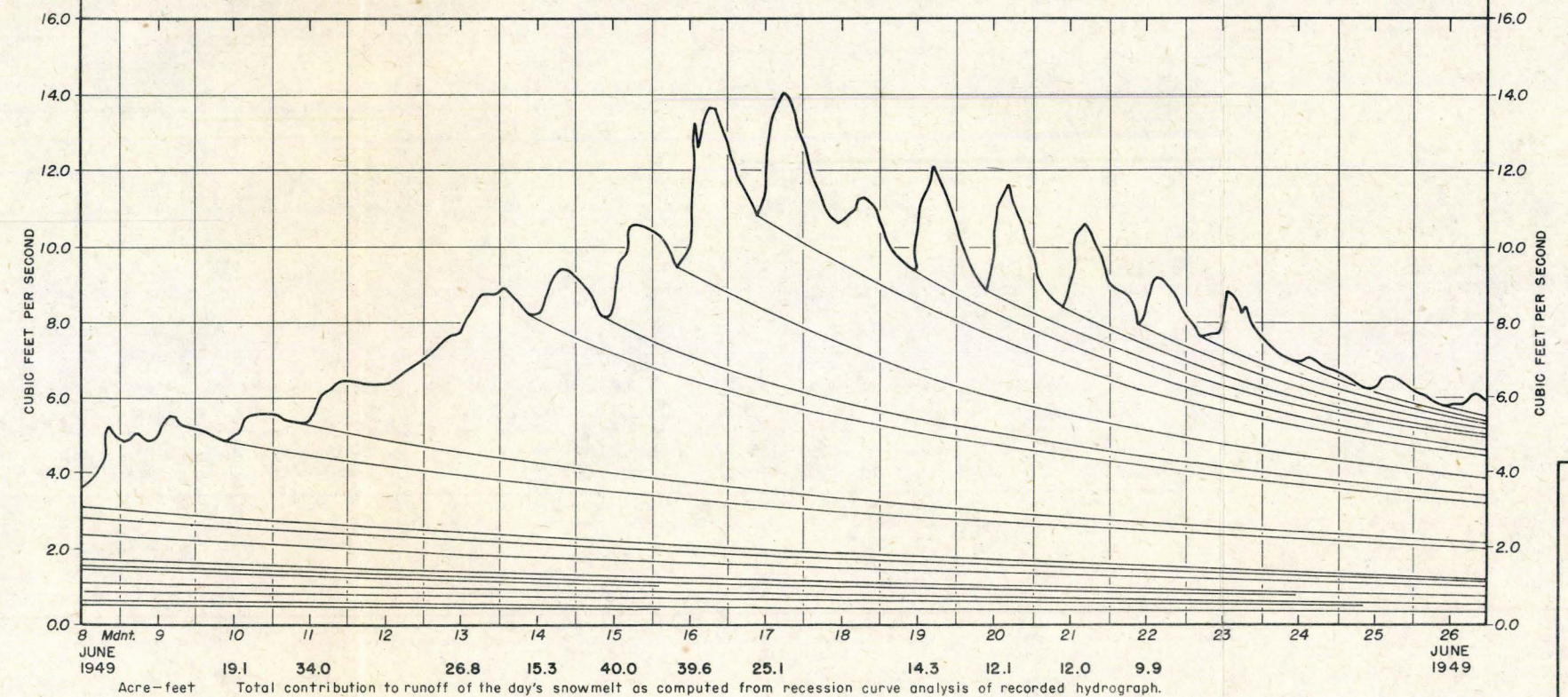
AIR TEMP. AT FOOL CREEK STATION

AIR TEMP. AT FOOL CREEK STATION



RUNOFF
(continued)

RUNOFF
(continued)



COOPERATIVE SNOW INVESTIGATIONS
UNITED STATES DEPARTMENT OF AGRICULTURE FOREST SERVICE ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION
UNITED STATES DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION PROJECT PLANNING DIVISION HYDROLOGY BRANCH
1949 SNOWMELT RUNOFF
AND
RELATED METEOROLOGICAL FACTORS
FOOL CREEK
AREA 1.11 SQUARE MILES
FRASER EXPERIMENTAL FOREST, COLORADO
3-18-51 R. F. S.

FIGURE 10
14

METHODS OF ANALYSIS

Two methods of analyzing the run-off from snowmelt were used: a statistical study of the factors causing snowmelt, and the use of a physical equation developed by Phillip Light (20).

1. The Statistical Approach. A study was made of the 1948 data to determine which hydrograph area of the three listed below correlated best with the causative variable, as represented by degree days above 32°F, (X_2). The three hydrograph areas considered were:

X_0 = Total volume of run-off for one day as represented by the area under the hydrograph for one day and above a base line of zero flow bounded by the vertical time lines at midnight.

X_1 = Total volume of run-off from one day's contribution as represented by the area under the hydrograph for one day including the residual flow generated on that day but excluding the residual flow from snow previously melted, (shown as Area 1 plus Area 2 in Figure 7).

X_{1A} = Net volume of run-off for one day as represented by the area under the hydrograph for one day and above the recession from the previous day, (shown as Area 1 in Figure 7).

For the 1948 season the adjusted correlation coefficients for these three simple correlations were:

$\bar{r} = 0.45$ for the Equation $X_0 = 4.227X_2 - 3.85$,

$\bar{r} = 0.50$ for the Equation $X_1 = 3.927X_2 - 1.66$, and

$\bar{r} = 0.65$ for the Equation $X_{1A} = 5.436X_2 - 3.19$

This shows that use of the recession principle is a definite improvement over the simple use of the flow that occurred during one day. It was not considered necessary to repeat these correlations using the 1949 data.

Multiple correlation analyses were computed relating the run-off to the various factors causing snowmelt. The 10 equations presented in Report No. 1 were recomputed using the calculus-derived run-off volumes, and 22 additional combinations of the variables were tried. These 32 equations were computed for the 1948 season, 1949 season, and for the combined 1948-49 seasons. Results of these analyses which have been completed are summarized in Tables 5, 6, and 7. Since the results of all the correlation analyses have not been evaluated, it is not known at the time of preparation of this progress report which combination of variables is best. The simple correlation equation 33 appears to be almost as good as the multiple correlations

SUMMARY OF MULTIPLE CORRELATIONS - 1948 - ST. LOUIS CREEK, COLORADO

Equa- tion Number	Dependent Variable	INDEPENDENT VARIABLES																		a	R	Equa- tion Number
		X ₂	X ₃	X ₄	X ₅	X ₆	X ₇	X ₈	X ₉	X ₁₀	X ₁₁	X ₁₂	X ₁₃	X ₁₄	X ₁₅	X ₁₆	X ₁₇	X ₁₈	X ₁₉			
1	X1.26	4.527				0.387														-4.84	0.48	1
1A	X1A.26	6.525				0.680														-8.84	0.66	1A
2	X1.27	3.452					0.129													-2.40	0.47	2
2A	X1A.27	5.965					0.172													-6.01	0.68	2A
3	X1.28	3.753						0.329												-2.01	0.47	3
3A	X1A.28	5.508						-0.295												-3.87	0.62	3A
4	X1.247	4.569		-0.628			0.292													-1.74	0.63	4
4A	X1A.247	5.600		0.206			-0.226													-2.22	0.61	4A
5	X1.257	2.235			1.731		0.426													-8.85	0.56	5
5A	X1A.257	5.483			0.841		-0.050													-5.10	0.63	5A
6	X1.267	4.056				0.788	0.342													-10.34	0.50	6
6A	X1A.267	6.498				0.704	0.020													-9.16	0.63	6A
7	X1.268	5.847				1.608		1.822												-17.42	0.60	7
7A	X1A.268	7.171				1.277		0.892												-14.99	0.66	7A
8	X1.269	4.926				1.408			1.528											-16.13	0.61	8
8A	X1A.269	6.677				1.069			0.582											-13.13	0.65	8A
9	X1.467			-0.429		-0.109	0.510													2.22	0.25	9
9A	X1A.467			0.710		0.902	0.279													-7.87	0.20	9A
10	X1.6710					0.242	0.511			-0.023										-2.03	0.0	10
10A	X1A.6710					1.106	0.255			0.158										-8.82	0.25	10A
11	X1.710 19						0.546			-0.023									0.315	-2.87	0.0	11
11A	X1A.710 19						0.287			0.140									0.964	-7.75	0.25	11A
12	X1.711 13						0.238				-0.158		8.785							-9.83	0.67	12
12A	X1A.711 13						-0.237				3.414		2.447							-17.86	0.62	12A
13	X1.712 13						0.316					-0.158	9.943							-11.82	0.69	13
13A	X1A.712 13						-0.229					0.634	0.292							1.11	0.53	13A
14	X1.71719						0.333										2.735		0.530	-6.49	0.48	14
14A	X1A.71719						0.003										4.921		0.475	-4.86	0.72	14A
15	X1.15 17 19														0.289		2.837		0.468	-5.48	0.46	15
15A	X1A.15 17 19														0.042		4.887		0.520	-5.47	0.72	15A
16	X1.15 18 19														0.295			3.309	0.549	-4.71	0.37	16
16A	X1A.15 18 19														-0.010			6.528	0.693	-4.41	0.72	16A
17	X1.16 17 19															0.660	3.456		0.854	-9.83	0.53	17
17A	X1A.16 17 19															0.132	4.997		0.616	-6.59	0.72	17A
18	X1.2457	4.093		-0.539	0.516		0.352													-3.77	0.61	18
18A	X1A.2457	3.258		0.645	2.296		0.038													-11.18	0.69	18A
19	X1.2467	4.622		-0.591		0.153	0.325													-3.35	0.60	19
19A	X1A.2467	6.020		0.497		1.239	0.037													-15.10	0.68	19A
20	X1.2468	6.468		-0.632		0.990		1.879												-10.64	0.70	20
20A	X1A.2468	6.696		0.484		1.750		0.848												-20.16	0.70	20A
21	X1.267 10	4.279				0.470	0.343			-0.052										-7.27	0.47	21
21A	X1A.267 10	5.992				1.422	0.020			0.117										-16.13	0.68	21A
22	X1.267 14	7.192				1.008	0.055							-0.490						-10.67	0.64	22
22A	X1A.267 14	5.369				0.628	0.125							0.176						-9.08	0.62	22A
23	X1.3457		0.398	-0.493	1.259		0.478													-3.16	0.52	23
23A	X1A.3457		0.418	0.573	2.666		0.102													-9.35	0.67	23A
24	X1.3467		0.604	-0.818		-0.049	0.309													+3.93	0.47	24
24A	X1A.3467		0.867	0.149		0.981	-0.012													-5.36	0.59	24A
25	X1.67 11 13					0.762	0.477				-0.099		9.295							-18.11	0.70	25
25A	X1A.67 11 13					0.377	-0.118				3.444		2.700							-21.96	0.60	25A
26	X1.67 12 13					0.710	0.489					-0.066	9.709							-18.52	0.71	26
26A	X1A.67 12 13					0.917	-0.005					0.752	-0.009							-7.54	0.56	26A
27	X1.14 15 18 19													-0.414	-0.050			5.720	0.570	-1.22	0.48	27
27A	X1A.14 15 18 19													0.143	0.109			5.694	0.686	-5.62	0.70	27A
28	X1.67 11 13 14					0.782	0.246				0.806		30.487	-0.333						-21.47	0.76	28
28A	X1A.67 11 13 14					0.363	0.049				2.787		1.836	0.241						-19.52	0.60	28A
29	X1.67 12 13 14					0.942	0.247					0.217	9.724	-0.363						-18.05	0.76	29
29A	X1A.67 12 13 14					0.782	0.136					0.588	-0.018	0.212						-7.81	0.54	29A
30	X1.11 13 14 15 19										0.241		11.383	-0.286	0.627				1.077	-24.67	0.81	30
30A	X1A.11 13 14 15 19										2.528		2.341	0.263	0.297				0.688	-23.05	0.63	30A
32	X1.11										1.559									- 5.71	0.28	32
32A	X1A.11										3.261									-16.05	0.64	32A
33	X1.2	3.927																		-1.66	0.50	33
33A	X1A.2	5.430																		-3.19	0.65	33A

LIST OF VARIABLES USED IN MULTIPLE CORRELATION ANALYSIS OF DAILY SNOWMELT

Identi- fication	Description of variable	Units	Identi- fication	Description of variable	Units	Identi- fication	Description of variable	Units
X ₁	Total run-off from 1 day's contribution to the hydrograph	100 acre-ft	X ₇	Daily wind travel at 47.4 feet in open	10 mile	X ₁₄	Accumulated run-off April 1 to start of day plus recession in percentage of total run-off from April 1 to July 31	10 percent
X _{1A}	First day run-off volume above recession	10 acre-feet	X ₈	Daily wind travel at 1.4 feet in forest	10 mile	X ₁₅	Daily wind travel at 23.1 feet in open	10 mile
X ₂	Degree-days above 32° F at Headquarters	10° days	X ₉	Daily wind travel at 24.9 feet in forest	10 mile	X ₁₆	Daily wind travel at 1.4 feet in open	10 mile
X ₃	Degree-days above 50° F at Headquarters	° days	X ₁₀	1000 to 1400 hour solar radiation at Shadow Mountain	10 Ly	X ₁₇	Degree-days above 32° F at Wind Tower	10° days
X ₄	Daily total solar radiation at Shadow Mountain	100 Ly	X ₁₁	Maximum temperature at Headquarters	10° F	X ₁₈	Degree-days above 40° F at Wind Tower	10° days
X ₅	Dew point temperature at Headquarters	10° F	X ₁₂	Degree-days above 40° F at Headquarters	° days	X ₁₉	Relative humidity at Wind Tower	10 percent
X ₆	Relative humidity at Headquarters	10 percent	X ₁₃	Duration of temperature above 40° F at Headquarters	10 hours			

TABLE 5. Summary of multiple correlations, 1948

SUMMARY OF MULTIPLE CORRELATIONS - 1949 - ST. LOUIS CREEK, COLORADO

Equation Number	Dependent Variable	INDEPENDENT VARIABLES																		a	R	Equation Number
		X ₂	X ₃	X ₄	X ₅	X ₆	X ₇	X ₈	X ₉	X ₁₀	X ₁₁	X ₁₂	X ₁₃	X ₁₄	X ₁₅	X ₁₆	X ₁₇	X ₁₈	X ₁₉			
1	X1.26	3.005				-0.240														+0.97	0.57	1
1A	X1A.26	5.694				0.475														-6.91	0.81	1A
2	X1.27	2.938					0.155													-2.15	0.57	2
2A	X1A.27	4.464					0.074													-2.74	0.63	2A
3	X1.28	3.340						0.306												-1.46	0.56	3
3A	X1A.28	4.685						0.087												-2.38	0.80	3A
4	X1.247	2.886		0.049			0.137													-2.13	0.54	4
4A	X1A.247	4.869		-0.388			0.217													-2.55	0.80	4A
5	X1.257	2.997			-0.116		0.136													-1.67	0.54	5
5A	X1A.257	3.717			1.440		0.282													-8.56	0.81	5A
6	X1.267	2.851				-0.083	0.132													-1.24	0.54	6
6A	X1A.267	5.336				0.841	0.308													-12.06	0.81	6A
7	X1.268	3.054				-0.184		0.128												+0.38	0.54	7
7A	X1A.268	6.057				0.885		0.940												-11.24	0.81	7A
8	X1.269	3.004				-0.243			-0.004											-2.30	0.54	8
8A	X1A.269	5.879				1.050			0.752											-13.30	0.82	8A
9	X1.467			-0.124		-0.887	0.294													7.18	0.45	9
9A	X1A.467			-0.319		-0.763	0.614													4.89	0.59	9A
10	X1.67 10					0.013	0.320			0.121										-2.92	0.48	10
10A	X1A.67 10					-0.205	0.621			0.028										-1.50	0.58	10A
11	X1.7 10 19						0.290			0.112									-0.101	-1.62	0.48	11
11A	X1A.7 10 19						0.650			0.041									-0.060	-3.11	0.58	11A
12	X1.7 11 13						0.417				-0.606		3.065							-2.71	0.54	12
12A	X1A.7 11 13						0.213				0.496		4.632							-7.58	0.79	12A
13	X1.7 12 13						0.216					0.097	2.741							-3.38	0.54	13
13A	X1A.7 12 13						0.127					0.182	4.059							-4.31	0.80	13A
14	X1.7 17 19						0.042										2.769		-0.253	+1.12	0.53	14
14A	X1A.7 17 19						0.226										5.525		0.744	-10.37	0.85	14A
15	X1.15 17 19														0.050		2.780		-0.246	1.03	0.55	15
15A	X1A.15 17 19														0.195		5.630		0.690	-9.70	0.85	15A
16	X1.15 18 19														0.071			3.644	-0.055	0.64	0.54	16
16A	X1A.15 18 19														0.210			7.880	1.188	-11.28	0.84	16A
17	X1.16 17 19															0.095	2.833		-0.221	0.87	0.55	17
17A	X1A.16 17 19															0.511	5.867		0.922	-11.73	0.86	17A
18	X1.2457	2.864		0.057	0.027		0.136													-2.27	0.51	18
18A	X1A.2457	4.104		-0.166	1.020		0.283													-6.78	0.80	18A
19	X1.2467	2.841		0.014		-0.079	0.128													-1.26	0.50	19
19A	X1A.2467	5.298		-0.060		0.743	0.303													-10.95	0.80	19A
20	X1.2468	3.054		0.040		-0.136		0.136												-0.18	0.50	20
20A	X1A.2468	6.082		0.100		1.023		0.976												-12.82	0.80	20A
21	X1.267 10	2.720				0.512	0.156			0.103										-7.93	0.43	21
21A	X1A.267 10	5.324				0.773	0.300			-0.008										-11.29	0.80	21A
22	X1.267 14	6.673				0.495	-0.026							-0.631						-4.93	0.64	22
22A	X1A.267 14	5.240				0.826	0.312							0.016						-11.96	0.80	22A
23	X1.3457		0.172	0.407	1.680		0.339													-8.40	0.46	23
23A	X1A.3457		0.358	0.187	3.057		0.521													-13.45	0.76	23A
24	X1.3467		0.284	-0.240		-0.578	0.210													-4.02	0.45	24
24A	X1A.3467		0.625	-0.572		-0.084	0.478													-4.51	0.70	24A
25	X1.67 11 13					-0.764	0.238				-1.307		4.322							8.08	0.54	25
25A	X1A.67 11 13					0.237	0.269				0.714		4.521							-10.92	0.78	25A
26	X1.67 12 13					-0.497	0.125					-0.013	3.158							1.22	0.52	26
26A	X1A.67 12 13					0.660	0.248					0.328	3.505							-10.42	0.80	26A
27	X1.14 15 18 19													-0.723	-0.258			9.856	0.815	-2.08	0.65	27
27A	X1A.14 15 18 19													-0.152	0.141			9.183	1.370	-11.85	0.84	27A
28	X1.67 11 13 14					-0.503	0.077				-0.050		4.637	0.323						-2.13	0.63	28
28A	X1A.67 11 13 14					0.048	0.385				-0.195		4.293	0.234						-6.42	0.78	28A
29	X1.67 12 13 14					0.410	-0.102					0.518	3.186	-0.596						-3.22	0.59	29
29A	X1A.67 12 13 14					0.528	0.281					0.251	3.501	0.086						-9.78	0.79	29A
30	X1.11 13 14 15 19										-0.101		4.657	-0.312	0.036				-0.574	2.96	0.55	30
30A	X1A.11 13 14 15 19										-0.189		4.388	0.240	0.427				0.059	-6.70	0.78	30A
32	X1.11										1.864									-7.85	0.48	32
32A	X1A.11										2.707									-12.29	0.73	32A
33	X1.2	3.486																		-1.32	0.59	33
33A	X1A.2	4.719																		-2.23	0.81	33A

LIST OF VARIABLES USED IN MULTIPLE CORRELATION ANALYSIS OF DAILY SNOWMELT

Identification	Description of variable	Units	Identification	Description of variable	Units	Identification	Description of variable	Units
X ₁	Total run-off from 1 day's contribution to the hydrograph	100 acre-feet	X ₇	Daily wind travel at 47.4 feet in open	10 mile	X ₁₄	Accumulated run-off April 1 to start of day plus recession in percentage of total run-off from April 1 to July 31	10 percent
X _{1A}	First day run-off volume above recession	10 acre-feet	X ₈	Daily wind travel at 1.4 feet in forest	10 mile	X ₁₅	Daily wind travel at 23.1 feet in open	10 mile
X ₂	Degree-days above 32° F at Headquarters	10° days	X ₉	Daily wind travel at 24.9 feet in forest	10 mile	X ₁₆	Daily wind travel at 1.4 feet in open	10 mile
X ₃	Degree-days above 50° F at Headquarters	° days	X ₁₀	1000 to 1400 hour solar radiation at Shadow Mountain	10 Ly	X ₁₇	Degree-days above 32° F at Wind Tower	10° days
X ₄	Daily total solar radiation at Shadow Mountain	100 Ly	X ₁₁	Maximum temperature at Headquarters	10° F	X ₁₈	Degree-days above 40° F at Wind Tower	10° days
X ₅	Dew point temperature at Headquarters	10° F	X ₁₂	Degree-days above 40° F at Headquarters	° days	X ₁₉	Relative humidity at Wind Tower	10 percent
X ₆	Relative humidity at Headquarters	10 percent	X ₁₃	Duration of temperature above 40° F at Headquarters	10 hours			

TABLE 6. Summary of multiple correlations, 1949

SUMMARY OF MULTIPLE CORRELATIONS - 1948 and 1949 - ST. LOUIS CREEK, COLORADO

Equation Number	Dependent Variable	INDEPENDENT VARIABLES																			a	R	Equation Number
		X ₂	X ₃	X ₄	X ₅	X ₆	X ₇	X ₈	X ₉	X ₁₀	X ₁₁	X ₁₂	X ₁₃	X ₁₄	X ₁₅	X ₁₆	X ₁₇	X ₁₈	X ₁₉				
1	X _{1.26}	3.368				-0.116														-0.26	0.59	1	
1A	X _{1A.26}	5.684				0.389														-6.11	0.79	1A	
2	X _{1.27}	3.037					0.156													-2.20	0.60	2	
2A	X _{1A.27}	4.855					-0.0003													0.59	0.79	2A	
3	X _{1.28}	3.377						0.360												-1.53	0.60	3	
3A	X _{1A.28}	4.833						0.031												-7.43	0.78	3A	
4	X _{1.247}	3.289		-0.208			0.232													-2.09	0.57	4	
4A	X _{1A.247}	4.950		-0.078			0.028													-3.35	0.81	4A	
5	X _{1.257}	2.813			0.432		0.229													-4.00	0.59	5	
5A	X _{1A.257}	4.396			0.876		0.149													-6.08	0.80	5A	
6	X _{1.267}	3.129				0.094	0.185													-3.25	0.58	6	
6A	X _{1A.267}	5.447				0.598	0.184													-9.08	0.79	6A	
7	X _{1.268}	3.707				0.219		0.568												-3.71	0.58	7	
7A	X _{1A.268}	6.227				0.924		0.906												-11.61	0.81	7A	
8	X _{1.269}	3.376				0.004			0.206											-1.67	0.58	8	
8A	X _{1A.269}	5.698				0.582			0.331											-8.38	0.79	8A	
9	X _{1.467}			-0.302		-0.822	0.380													6.91	0.48	9	
9A	X _{1A.467}			0.267		-0.051	0.525													-2.96	0.55	9A	
10	X _{1.67 10}					-0.189	0.384			0.045										-0.26	0.48	10	
10A	X _{1A.67 10}					0.118	0.532			0.080										-3.91	0.56	10A	
11	X _{1.7 10 19}						0.362			0.044									-0.229	0.26	0.48	11	
11A	X _{1A.7 10 19}						0.560			0.084									0.190	-4.86	0.56	11A	
12	X _{1.7 11 13}						0.344				-0.119		3.759							-4.40	0.59	12	
12A	X _{1A.7 11 13}						0.013				1.714		3.300							-10.94	0.77	12A	
13	X _{1.7 12 13}						0.234					0.093	3.070							-3.81	0.59	13	
13A	X _{1A.7 12 13}						0.012					0.331	2.988							-2.66	0.77	13A	
14	X _{1.7 17 19}						0.125										2.875		-0.062	-1.05	0.59	14	
14A	X _{1A.7 17 19}						0.119										5.327		0.483	-7.09	0.84	14A	
15	X _{1.15 17 19}														0.123		2.921		-0.067	-0.94	0.59	15	
15A	X _{1A.15 17 19}														0.130		5.361		0.492	-7.19	0.84	15A	
16	X _{1.15 18 19}														0.109			3.736	0.056	-0.45	0.57	16	
16A	X _{1A.15 18 19}														0.072			7.302	0.785	-6.73	0.83	16A	
17	X _{1.16 17 19}															0.248	3.151		0.098	-2.34	0.60	17	
17A	X _{1A.16 17 19}															0.311	5.631		0.727	-0.18	0.85	17A	
18	X _{1.2457}	3.375		-0.229	-0.078		0.224													-2.83	0.58	18	
18A	X _{1A.2457}	3.882		0.210	1.343		0.154													-8.12	0.79	18A	
19	X _{1.2467}	3.165		-0.312		-0.299	0.165													1.33	0.58	19	
19A	X _{1A.2467}	5.486		0.250		0.847	0.146													-11.84	0.79	19A	
20	X _{1.2468}	3.651		-0.275		-0.166		0.471												0.63	0.58	20	
20A	X _{1A.2468}	6.263		0.326		1.361		1.003												-16.62	0.80	20A	
21	X _{1.267 10}	3.082				0.254	0.189			0.028										-5.02	0.57	21	
21A	X _{1A.267 10}	5.367				0.889	0.192			0.051										-12.30	0.79	21A	
22	X _{1.267 14}	6.730				0.623	-0.024							-0.572						-6.31	0.66	22	
22A	X _{1A.267 14}	5.159				0.555	0.201							0.046						-8.83	0.79	22A	
23	X _{1.3457}		0.289	-0.015	1.108		0.425													-5.12	0.53	23	
23A	X _{1A.3457}		0.424	0.349	2.476		0.332													-10.42	0.52	23A	
24	X _{1.3467}		0.379	-0.506		-0.594	0.227													0.98	0.50	24	
24A	X _{1A.3467}		0.732	-0.127		0.380	0.224													-2.27	0.70	24A	
25	X _{1.67 11 13}					-0.348	0.249				-0.402		3.892							0.43	0.58	25	
25A	X _{1A.67 11 13}					0.351	0.108				1.999		3.166							-15.81	0.76	25A	
26	X _{1.67 12 13}					-0.174	0.197					0.055	3.228							-2.19	0.58	26	
26A	X _{1A.67 12 13}					0.682	0.158					0.480	2.368							-9.01	0.78	26A	
27	X _{1.14 15 18 19}													-0.566	-0.252			8.084	0.520	0.01	0.67	27	
27A	X _{1A.14 15 18 19}													-0.043	0.045			7.634	0.820	-6.69	0.82	27A	
28	X _{1.67 11 13 14}					-0.088	0.078				0.644		4.734	-0.350						-5.14	0.62	28	
28A	X _{1A.67 11 13 14}					0.244	0.179				1.567		2.818	0.144						-13.51	0.76	28A	
29	X _{1.67 12 13 14}					0.582	-0.043					0.497	3.588	-0.540						-5.74	0.66	29	
29A	X _{1A.67 12 13 14}					0.591	0.186					0.427	2.325	0.065						-8.59	0.77	29A	
30	X _{1.11 13 14 15 19}										0.617		4.768	-0.346	0.079				-0.107	-4.85	0.62	30	
30A	X _{1A.11 13 14 15 19}										1.553		0.907	0.147	0.268				0.346	-14.88	0.77	30A	
32	X _{1.11}										1.858									-7.76	0.50	32	
32A	X _{1A.11}										2.743									-12.57	0.73	32A	
33	X _{1.2}	3.625																		-1.38	0.60	33	
33A	X _{1A.2}	4.868																		-2.44	0.79	33A	

LIST OF VARIABLES USED IN MULTIPLE CORRELATION ANALYSIS OF DAILY SNOWMELT

Identi- fication	Description of Variable	Units	Identi- fication	Description of Variable	Units	Identi- fication	Description of Variable	Unit
X ₁	Total run-off from 1 day's contribution to the hydrograph	100 acre-ft	X ₇	Daily wind travel at 47.4 feet in open	10 mile	X ₁₄	Accumulated run-off April 1 to start of day plus recession in percentage of total run-off from April 1 to July 31	10 percent
X _{1A}	First day run-off volume above recession	10 acre-ft	X ₈	Daily wind travel at 1.4 feet in forest	10 mile			
X ₂	Degree-days above 32° F at Headquarters	10° days	X ₉	Daily wind travel at 24.9 feet in forest	10 mile	X ₁₅	Daily wind travel at 23.1 feet in open	10 mile
X ₃	Degree-days above 50° F at Headquarters	° days	X ₁₀	1000 to 1400 hour solar radiation at Shadow Mountain	10 Ly	X ₁₆	Daily wind travel at 1.4 feet in open	10 mile
X ₄	Daily total solar radiation at Shadow Mountain	100 Ly	X ₁₁	Maximum temperature at Headquarters	10° F	X ₁₇	Degree-days above 32° F at Wind Tower	10° days
X ₅	Dew point temperature at Headquarters	10° F	X ₁₂	Degree-days above 40° F at Headquarters	° days	X ₁₈	Degree-days above 40° F at Wind Tower	10° days
X ₆	Relative humidity at Headquarters	10 percent	X ₁₃	Duration of temperature above 40° F at Headquarters	10 hours	X ₁₉	Relative humidity at Wind Tower	10 percent

TABLE 7. Summary of multiple correlations, 1948 - 1949

tried. This equation related the total run-off from one day's melt to the degree-days at headquarters as computed from the thermograph trace.

Another set of 32 correlations was run paralleling the first but using the net first day's run-off (X_{1A}) as the dependent variable. The results of these computations are also summarized in Tables 5, 6, and 7 (the equations are identified by the letter "A" following the equation number). Most of these correlations are better than those using the total run-off from one day's contribution (X_1). Here again, the simple correlation equation 33A with degree-days above 32°F (derived from hourly values) is almost as good as the best of the multiple correlations. Equations 18, 18A, 33, and 33A were used in the synthesis of the snowmelt hydrograph described in Section F.

2. The Physical Approach. Practically all of the heat utilized in the melting of snow can be ascribed ultimately to solar radiation. Solar radiation may supply heat for snowmelt in several ways, among which are: (a) by direct incidence upon the snow, (b) by reflected radiation resulting from incidence of solar radiation upon objects, and (c) indirectly as warmth in air, the temperature of which has been raised either by direct solar radiation or by contact with objects heated by the incidence of solar radiation. The amount of heat released to the annual snowmelt by the cooling of the earth is negligible compared to that received by the earth as solar radiation. Temperatures during the snowmelt season of the soil below the snow are usually very close to the freezing point of water, indicating that practically no heat is supplied for snowmelt by the soil during the spring season. *

When the snowmelt season is actively underway in the spring, the heat which is effective in the melting of snow is almost entirely active at the snow surface exposed to the air. Heat supplied by warm air blowing over the snow and from condensation of water vapor (which releases latent heat of vaporization) is very effective in the melting of snow.

In the physical approach of this analysis, use was made of an equation which expresses the physical relationship of wind, air temperature, and water vapor pressure as they interact to make heat available for melting and evaporation of snow. The melting formula developed by Light (20) from Sverdrup's (26) eddy-conductivity equation involving a theory of atmospheric turbulence was chosen for use in this approach. Light's equation, both in general form, and as reduced for application to the Fraser Experimental Forest data is shown in Figure 11.

Air-temperature data from the thermograph at the wind tower in the open was used in Light's equation directly without adjustment for lapse rate within the Fraser Experimental Forest. No lapse-rate adjustment was made, as observations in the field have disclosed that, although snow accumulation ordinarily takes place by elevation zones, snow disappearance in a mountainous region takes place by aspects (orientation or direction of exposure of the slopes). Observations by

PHILLIP LIGHT'S EQUATION*

A. General statement:

$$D = \frac{\rho k_0^2}{80 \ln(a/z_0) \ln(b/z_0)} U [c_p T + (e - 6.11) 423/p]$$

in cgs units

D = effective snowmelt

ρ = density of air

k_0 = von Karman's coefficient = 0.38

ln = natural logarithm

a = elevation of anemometer in mb at hygrothermograph level

z_0 = roughness parameter = 0.25

b = elevation of hygrothermograph

U = wind velocity at anemometer level

c_p = specific heat of air at constant pressure = 0.24

T = air temperature at hygrothermograph level

e = vapor pressure of air

p = atmospheric pressure in mb

B. As reduced and applied to Fraser Experimental Forest data:

$$D = KU_M [0.00175(T_F - 32)10^{-0.0000156h} + 0.00550(e - 6.11)]$$

D = effective snowmelt in inches per six hours

K = basin coefficient

U_M = average wind velocity in miles per hour at fifty foot level

T_F = average air temperature in degrees F. at 7.5 foot level

h = station elevation in feet above sea level

e = average vapor pressure in mb at 7.5 foot level

6.11 = vapor pressure in mb at 32° F. dew point

$$D = KU_M [0.0012(T_F - 32) + 0.0055(e - 6.11)]$$

* See reference (20)

Daniels (12, pp. 185-186) substantiate this broadly characteristic progression in the disappearance of snow. The results of the application of Light's equation to snowmelt run-off for the 1948 and 1949 snowmelt seasons are given for St. Louis Creek in Table 8 and for Fool Creek in Table 9. The value of the St. Louis Creek basin coefficient K, in Light's equation, was found to be 0.890 for 1948 and 0.754 for 1949.

The value of the Fool Creek basin coefficient K as based upon depths of snowmelt computed from data at the wind tower in the open on West St. Louis Creek, was found to be 1.157 for 1948 and 0.889 for 1949.

FIGURE 11. Phillip Light's snowmelt and evaporation equation.

3. Effect of Instrument Errors. The relationship between the meteorological elements and the streamflow volumes will be affected by the quality of the measurements of these physical events. The following table shows the magnitude of the error introduced into the computed hydrograph volumes by: (a) constant errors which would occur if the individual temperature or humidity recording pens were not in proper position with reference to the chart scale, and (b) constant errors which would occur if both the pen and humidity records were affected by improper seating of the chart on the instrument drum, causing the chart to ride uniformly above the base line through its circumference.

COMPARISON OF SNOWMELT COMPUTED FROM
LIGHT'S EQUATION 1948 AND 1949

St. Louis Creek, Colorado
Area = 32.8 Square Miles

Date 1948	Melt computed by Light's Equation	Run-off volume measured	Departure of computed from measured volume		Date 1949	Melt computed by Light's Equation	Run-off volume measured	Departure of computed from measured volume	
	inch	inch	inch	%		inch	inch	inch	%
May 14	0.144	0.336	-0.192	-57.1	May 23	0.076	0.066	0.010	15.2
15	0.071	0.186	-0.115	-61.8	24	0.173	0.113	0.060	53.1
16	0.134	0.231	-0.097	-42.0	25	0.150	0.198	-0.048	24.2
19	0.487	0.278	0.209	75.2	26	0.293	0.262	0.031	11.8
20	0.369	0.392	-0.023	- 5.9	27	0.292	0.167	0.125	74.8
21	0.422	0.320	0.102	31.9	June 1	0.012	-0.039	0.051	-130.8
22	0.258	0.224	0.034	15.2	2	0.033	-0.001	0.034	3400.0
23	0.167	0.162	0.005	3.1	3	0.112	0.116	-0.004	-3.4
24	0.227	0.106	0.121	114.2	4	0.167	0.187	-0.020	-10.7
27	0.208	0.319	-0.111	-34.8	5	0.326	0.340	-0.014	-4.1
28	0.168	0.167	0.001	0.6	6	0.137	0.102	0.035	34.3
29	0.119	0.125	-0.006	- 4.8	7	0.187	0.069	0.118	171.0
30	0.455	0.358	0.097	27.1	8	0.195	0.380	-0.185	-48.7
31	0.439	0.290	0.149	51.4	9	0.221	0.204	0.017	8.3
June 1	0.491	0.462	0.029	6.3	10	0.246	0.239	0.007	2.9
2	0.524	0.339	0.185	54.6	15	0.340	0.451	-0.111	-24.6
3	0.262	0.276	-0.014	-5.1	16	0.774	0.732	0.042	5.7
4	0.207	0.148	0.059	39.9	17	0.704	0.364	0.340	93.4
5	0.379	0.206	0.173	84.0	18	0.361	-0.132	0.493	373.5
					19	0.499	0.347	0.152	43.8
					20	0.492	0.203	0.289	142.4
TOTALS	5.531	4.925	+0.606	+12.3		5.790	4.368	+1.422	+32.6

Basin Coefficient, $K = \frac{4.925}{5.531} = 0.890$
based on 1948 data

Basin Coefficient, $K = \frac{4.368}{5.790} = 0.754$
based on 1949 data

TABLE 8: COMPARISON OF ST. LOUIS CREEK SNOWMELT COMPUTED FROM LIGHT'S EQUATION, 1948 AND 1949.

COMPARISON OF SNOWMELT COMPUTED FROM
LIGHT'S EQUATION 1948 AND 1949

Fool Creek, Colorado
Area = 1.11 Square Miles

Date 1948	Melt computed by Light's Equation	Run-off volume measured	Departure of computed from measured volume		Date 1949	Melt computed by Light's Equation	Run-off volume measured	Departure of computed from measured volume	
	inch	inch	inch	%		inch	inch	inch	%
May 16	0.134	0.108	+0.026	+24.1	May 25	0.150	0.170	-0.020	-11.8
18	0.376	0.253	+0.123	+48.6	26	0.293	0.197	+0.096	+48.7
19	0.487	0.340	+0.147	+43.2	27	0.292	0.166	+0.126	+75.9
20	0.369	0.377	-0.008	- 2.1	June 4	0.167	0.357	-0.190	-53.2
21	0.422	0.528	-0.106	-20.1	5	0.326	0.380	-0.054	-14.2
22	0.258	0.333	-0.075	-22.5	10	0.246	0.323	-0.077	-23.8
23	0.167	0.369	-0.202	-54.7	15	0.340	0.676	-0.336	-49.7
28	0.168	0.267	-0.099	-37.1	16	0.774	0.669	+0.105	+15.7
29	0.119	0.345	-0.226	-65.5	17	0.704	0.424	+0.280	+66.0
30	0.455	0.748	-0.293	-39.2	19	0.499	0.242	+0.257	+106.2
31	0.439	0.378	+0.061	+16.1	20	0.492	0.205	+0.287	+140.0
June 1	0.491	0.500	-0.009	- 1.8					
2	0.524	0.523	+0.001	+ 0.2					
3	0.262	0.445	-0.183	-41.1					
4	0.207	0.329	-0.122	-37.1					
5	0.379	0.240	+0.139	+57.9					
TOTALS	5.257	6.083	-0.826	-13.6		4.283	3.809	+0.474	+12.4

Basin Coefficient, $K = \frac{6.083}{5.257} = 1.157$
based on 1948 data.

Basin Coefficient, $K = \frac{3.809}{4.283} = 0.889$
based on 1949 data.

TABLE 9: COMPARISON OF FOOL CREEK SNOWMELT COMPUTED FROM LIGHT'S EQUATION, 1948 AND 1949.

EFFECT OF ERRORS

Source of error	Error in Measurement		Error in Computed Daily Melt	
	Temperature	Relative Humidity	Computed from Light's equation	Computed from Equation 6*
Pens not in proper adjustment with respect to chart	1°		14%	7%
	3°		36%	21%
		3%	12%	4%
		10%	39%	15%
Chart riding high on instrument drum	-1°	-2%		-9%
	-3°	-6%		-27%

* Table 5

TABLE 10. Effect of errors in observed temperature and relative humidity on the computed hydrograph volumes using data for May 20, 1948.

In the above comparison, the errors in hydrograph volumes as computed by Light's equation were compared with errors computed by Equation 6, Table 5. This equation was used as it is based upon degree-days above 32°F, wind, and relative humidity, data essentially similar to that used in Light's equation. The magnitude of the errors would be different, of course, if other equations were to be used in this comparison.

The magnitude of the introduced errors in the above table emphasizes the need for proper calibration and maintenance of the hygrothermographs, and for proper application of any necessary corrections to the chart traces before tabulation of data. For consistent results, it is important that recorders be kept in good calibration. Procedures for calibrating the hygrothermograph are described in Section G, "Instrumentation".

E. CALCULATION OF EVAPORATION LOSSES FROM THE SNOW BLANKET DURING THE SNOWMELT SEASON.

The use of Light's equation (described in Section D, "Analysis of Rates of Snowmelt," and shown in Figure 11) to compute the evaporation from the snow surface, and the tabulations of daily totals of evaporation

loss as computed and adjusted by the basin coefficient K for both the 1948 and 1949 seasons were presented in Report No. 1. Computations have not been completed of the evaporation losses from the snow during the winter or pre-melt periods. A summary of the evaporation losses computed without the application of basin coefficient K for 1948 and 1949 snowmelt periods is presented in Table 11.

SUMMARY OF EVAPORATION FROM SNOW
COMPUTED BY LIGHT'S EQUATION, 1948 - 1949
ST. LOUIS CREEK, COLORADO

Total inches for 24-hour period including lag time					
1948			1949		
Date	Exclusive of periods having avg temp below 32°F	Including periods of avg temp below 32°F <u>2/</u>	Date	Exclusive of periods having avg temp below 32°F	Including periods of avg temp below 32°F <u>2/</u>
May 14 <u>1/</u>	0.226	0.276	May 19 <u>1/</u>	0.151	0.237
15 <u>1/</u>	0.171	0.276	20	0.174	0.174
16	0.164	0.164	21 <u>1/</u>	0.022	0.026
18	0.011	0.011	22	0.044	0.044
19	None	None	23 <u>1/</u>	0.161	0.167
20	0.071	0.071	24 <u>1/</u>	0.143	0.159
21	0.095	0.095	25 <u>1/</u>	0.166	0.167
22 <u>1/</u>	0.163	0.182	26 <u>1/</u>	0.108	0.114
23	0.039	0.039	27	0.036	0.036
24	0.013	0.013	June 1 <u>1/</u>	0.038	0.060
27	0.061	0.061	2 <u>1/</u>	0.094	0.102
28	0.027	0.027	3	0.059	0.059
29 <u>1/</u>	0.148	0.170	4	None	None
30	0.062	0.062	5	0.085	0.085
31	0.038	0.038	6	None	None
June 1	0.013	0.013	7	None	None
2	None	None	8	None	None
3	0.122	0.122	9	None	None
4	0.186	0.186	10	0.006	0.006
5	0.130	0.130	15	0.112	0.112
TOTAL	1.740	1.936	16	0.011	0.011
			17	None	None
			18	None	None
			19	0.031	0.031
			20	0.126	0.126
			TOTAL	1.567	1.716

1/ Days for which there is at least one 6-hour period having average temperature below 32°F.

2/ Not corrected for vapor pressure corresponding to average temperature dew point.

TABLE 11. Summary of evaporation from snow computed by Light's equation, 1948 and 1949.

F. SYNTHESIS OF THE SNOWMELT HYDROGRAPH.

St. Louis Creek

The preliminary analysis of the areas and shapes of the hydrograph as presented on page 13 in Report No. 1 and Figure 7, herein, were continued using data from both 1948 and 1949, separately and combined.

Figure 12, which is an extension of page 61 of Report No. 1, shows the relationship of the first day's volume, Area 1, to the total volume, Areas 1 and 2 of Figure 7. An attempt to reduce the scatter of these points by using two-day averages did not show a significant improvement. However, double-mass curves (Figure 13) of the accumulated first-day volumes and the accumulated total run-off for both 1948 and 1949 showed a definite change in slope at the point representing the day having the largest total run-off for that year.

It is to be noted that in 1948 the greatest contribution of one day's snowmelt occurred on June 1, whereas the instantaneous peak discharge occurred on June 3. In 1949 the greatest volume contribution from one day's melt occurred on June 16 and the instantaneous peak discharge occurred on June 17.

The explanation for the change in slope of the double-mass curve is not readily apparent, but it is suggested that this may be due to a combination of factors that so far have not been considered in the investigations, such as: dwell time of available heat and area of contributing snow. However, this change in slope of the double-mass curve suggested consideration of the two parts of the melt season separately.

On Figure 12, the two outside lines represent the regression lines for the separate periods. A glance at the correlation coefficients will also show how this separation has improved the correlation for the days before the peak. The correlation coefficient is 0.80 when considering all the points. However, the days before the peak have a correlation coefficient of 0.90, a marked improvement. The days after the peak have a coefficient of 0.79, about the same as when all the points are considered.

Figure 14, an extension of page 59 in Report No. 1, shows the relation between the height to the peak and the first-day volume. As would be expected, this gave a good correlation coefficient of 0.98. Figure 15 is a combination of Figures 12 and 14, and shows directly the relation between height to the peak and total volume of run-off from one day's melt. As in Figure 12, the period before the maximum day shows a good relationship with a coefficient of correlation of 0.85. After the maximum day the points are widely scattered with a correlation coefficient of only 0.65. The relationship of height to trough with total run-off from one day's melt is very good, as shown in Figure 16. Coefficient of correlation is 0.97.

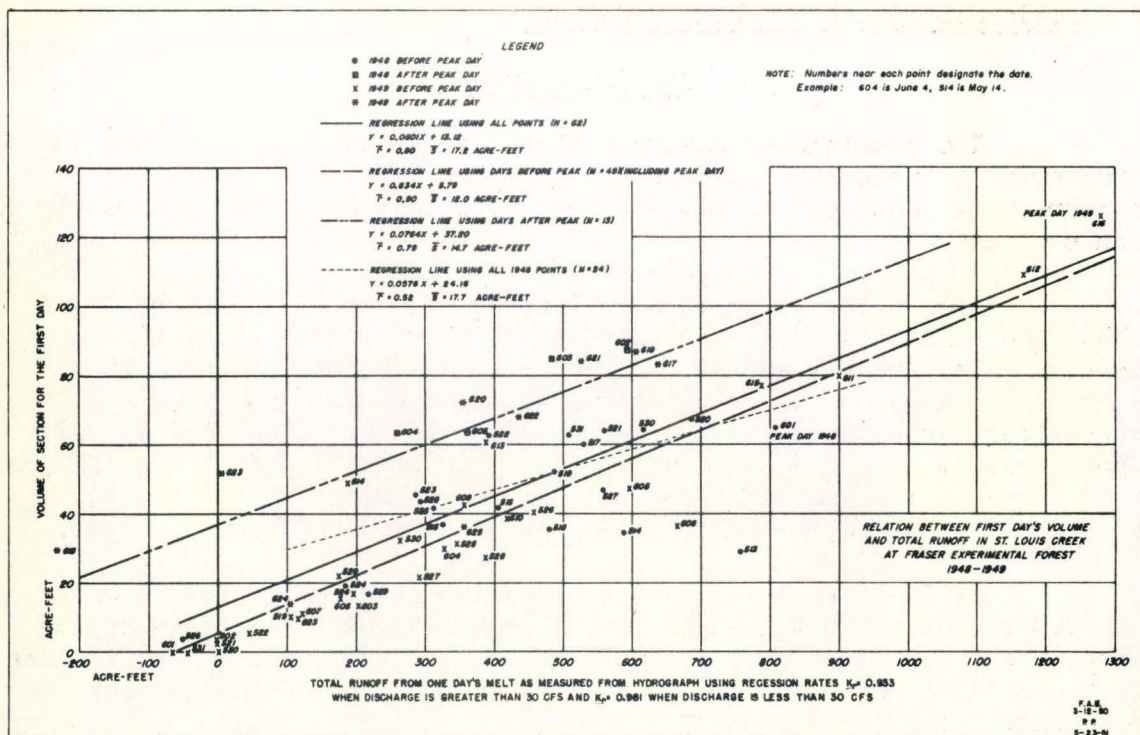


FIGURE 12. Relation between first-day volume and total run-off in St. Louis Creek.

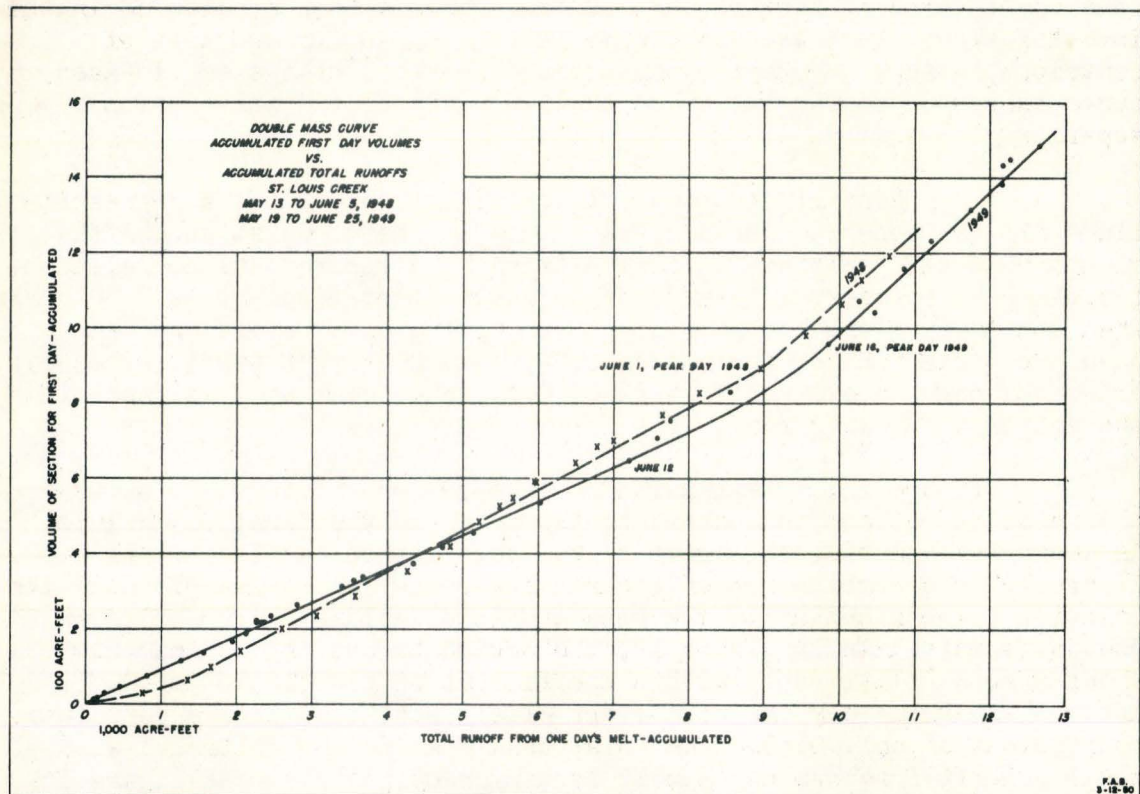


FIGURE 13. Double mass curve, accumulated first-day volumes vs. accumulated total run-offs, St. Louis Creek.

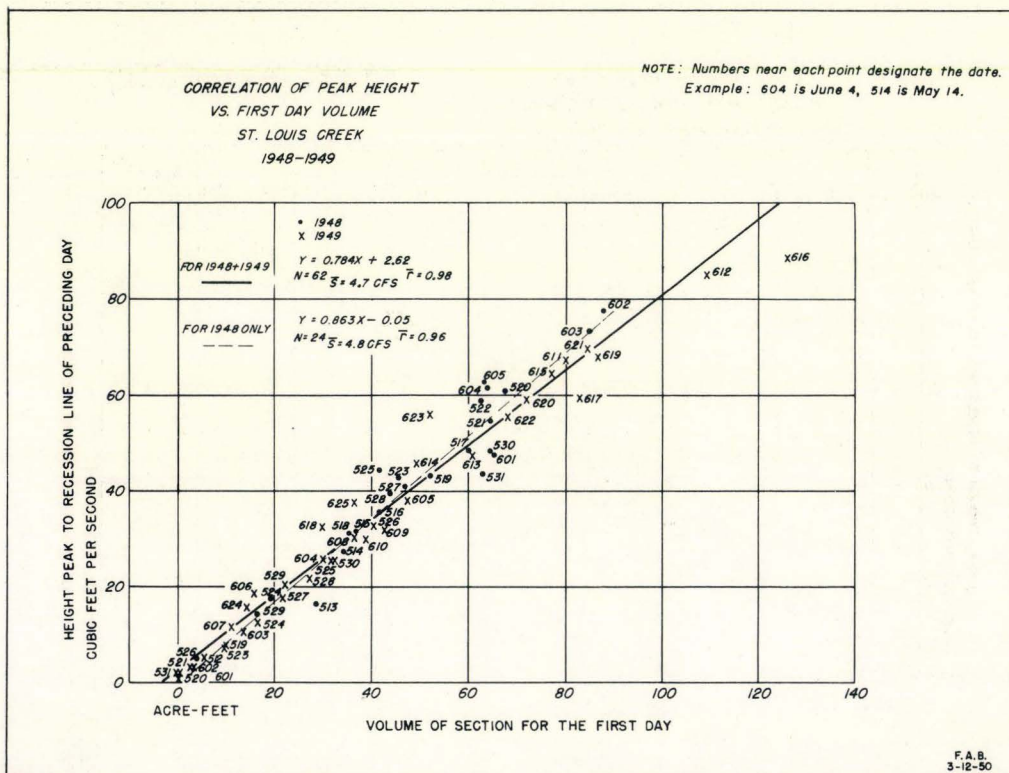


FIGURE 14. Correlation of peak height to first-day volume, St. Louis Creek.

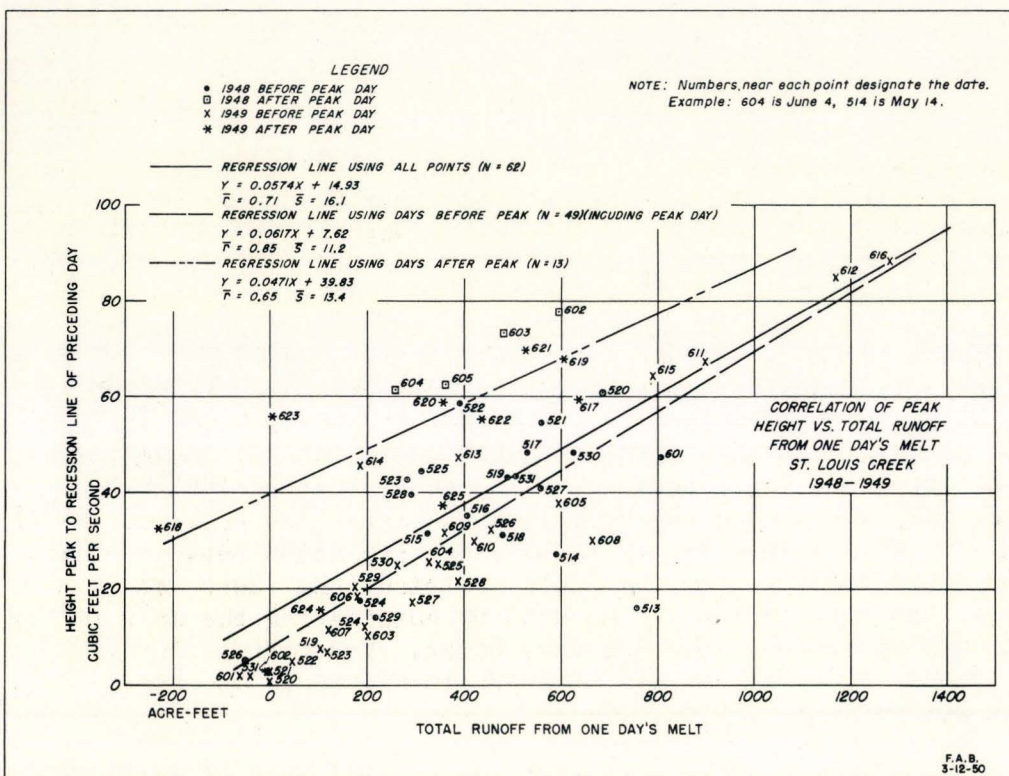


FIGURE 15. Correlation of peak height to total run-off, St. Louis Creek.

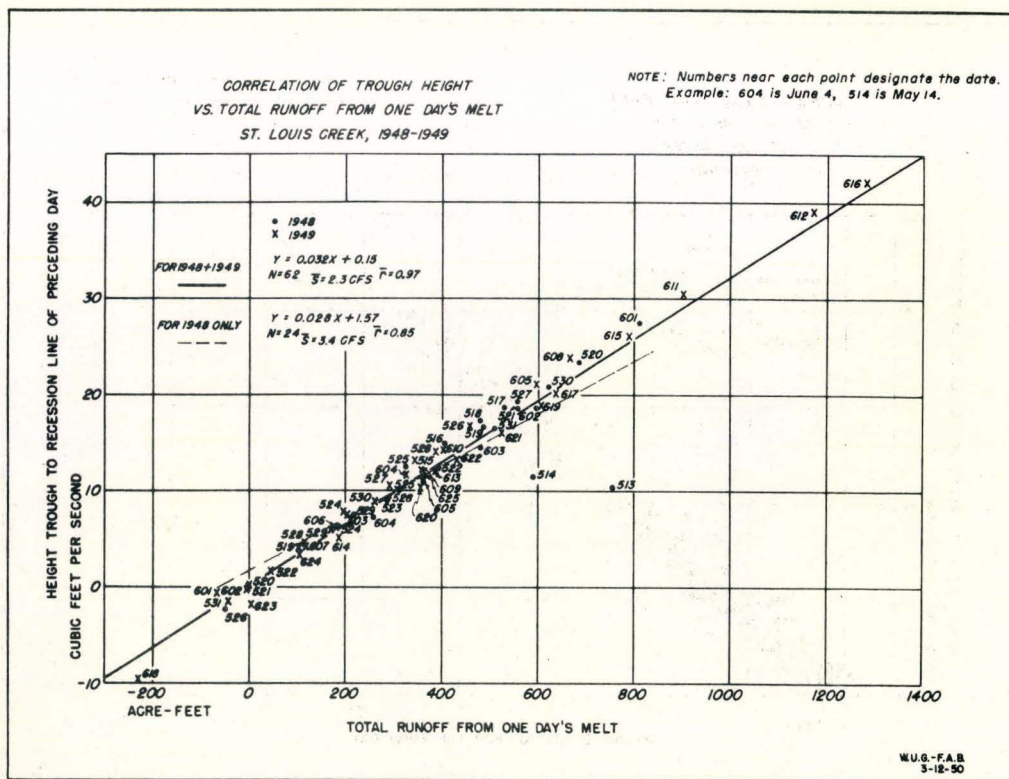


FIGURE 16. Correlation of trough height to total run-off, St Louis Creek.

Fool Creek

Geometrical relations of the shape of the daily melt hydrograph for Fool Creek were plotted in the same manner as for St. Louis Creek discussed above and showed the same general relationships. The maximum run-off day at Fool Creek occurred one day earlier than the maximum day in St. Louis Creek in both 1948 and 1949.

Figure 17 shows the definite break in the double-mass curve of accumulated first-day volume in relation to accumulated total daily run-offs similar to the double-mass curves for St. Louis Creek in Figure 13. Figure 18 shows the relation between first-day volume and total run-off from one day's melt and shows that dividing the total into two periods, one before the peak, and one after the peak, definitely improves the relationship. Figure 19 is the correlation between height to peak and total run-off from one day's contribution. Here again, as in Figure 18, the correlation is improved by considering the days before the maximum day separately from the days after. The correlation of height to trough vs. total run-off is shown in Figure 20 and has a correlation coefficient of 0.89.

It is of interest to note that the general type of relationship between the peak, trough, and volumes is apparent in both basins, although the St. Louis Creek drainage basin (32.8 square miles) is 30 times larger than the Fool Creek drainage basin (1.11 square miles).

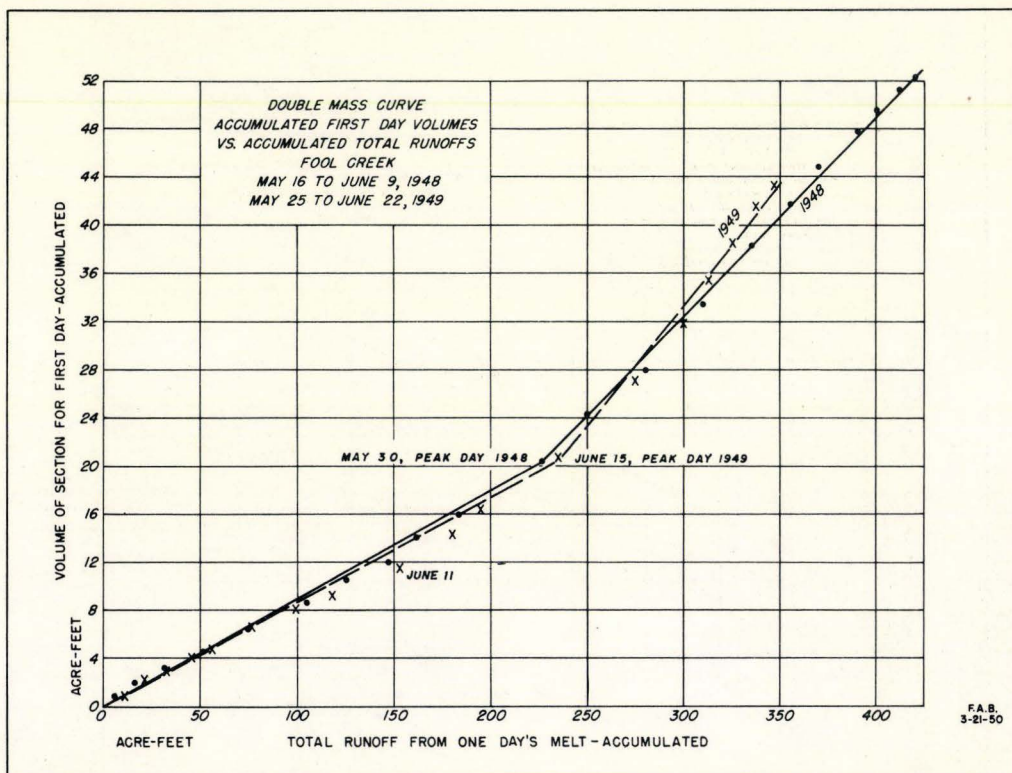


FIGURE 17. Double-mass curve, accumulated first-day volume vs. accumulated total run-off in Fool Creek.

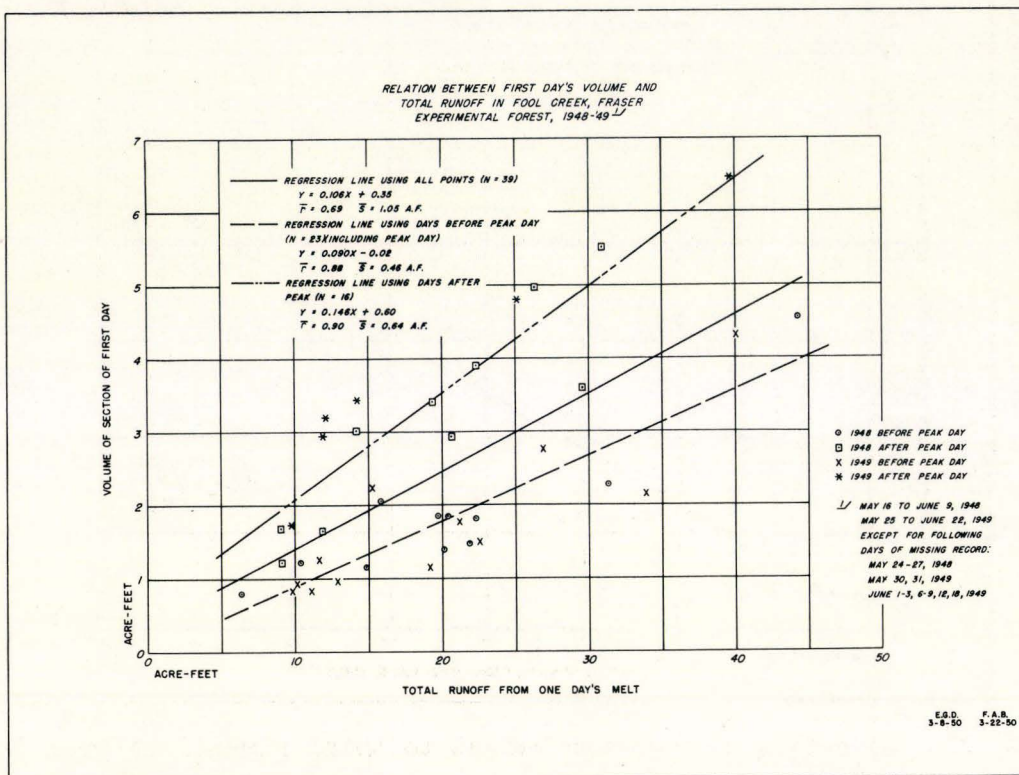


FIGURE 18. Relation between first-day volume and total run-off in Fool Creek.

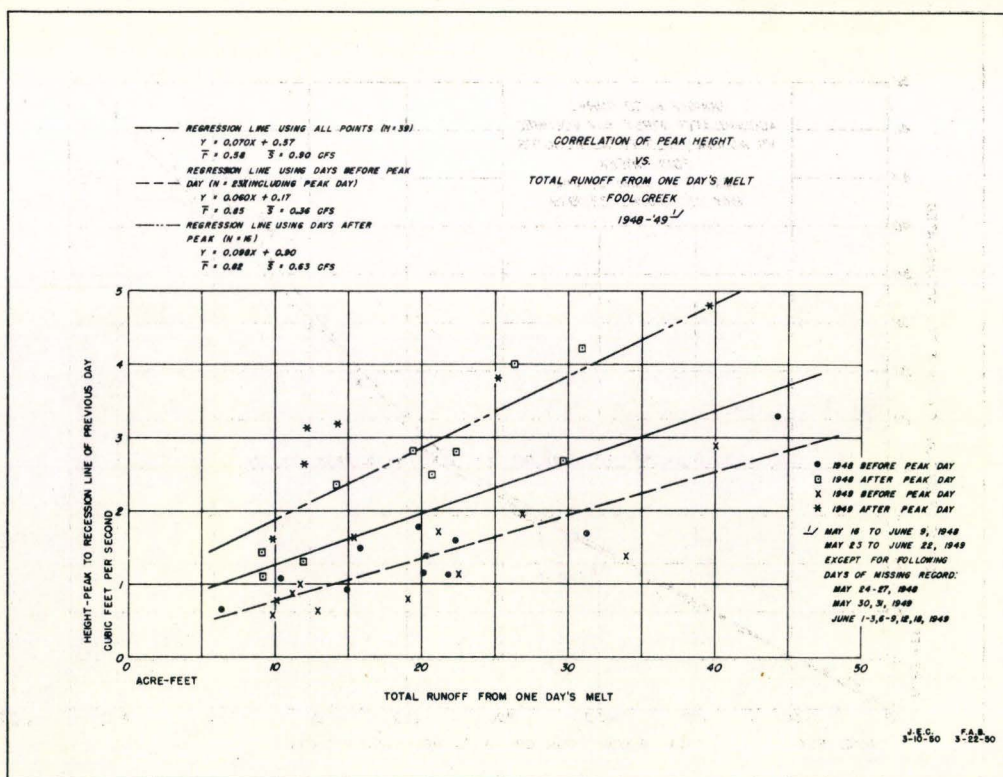


FIGURE 19. Correlation of peak height to total run-off in Fool Creek.

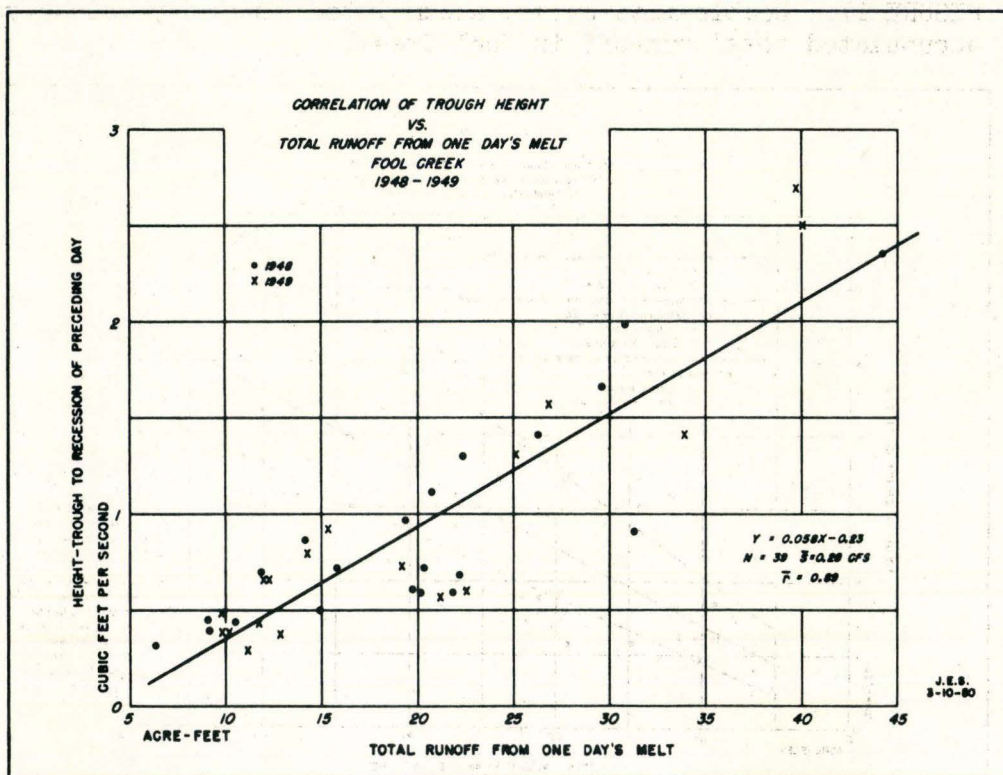


FIGURE 20. Correlation of trough height to total run-off in Fool Creek.

FORECASTING RATES OF RUN-OFF FROM SNOWMELT

By means of the snow measurements described in Paragraph 6, Section G, "Instrumentation," and their application to appropriately developed empirical relationships between water equivalent of the snow-pack on the watershed, among other data, and resulting streamflow, it is possible to make advance estimates of the volume of the seasonal run-off. For purposes of project development studies and mostly for use in the operation of water conservation projects, further refinement of the seasonal forecasts and estimates of the momentary seasonal peak discharge, as well as the daily stream flows, are desired and necessary as the run-off season progresses.

The purpose of this part of the investigations is to develop and test a method of forecasting the rates of run-off from snowmelt (in effect, the shape of the snowmelt hydrograph) using observed meteorological data. As distinguished from methods of forecasting the seasonal peak rate of run-off based upon relationships between the seasonal peak and the seasonal volume of water-yield, not discussed here, this analysis is based upon the application of heat units.

This method of forecasting rates of run-off from snowmelt makes use of the recession characteristics of stream flow from snowmelt discussed in the preceding Section D, "Analysis of Rates of Snowmelt," and of the area relationships shown in Figure 7. As explained in Section D, analysis of previous years' hydrographs has demonstrated that run-off of St. Louis Creek does not all occur on the day when the snow melts. There is considerable lag due probably to ground storage characteristics of this particular watershed. For any given watershed, the magnitude of this phenomenon can only be evaluated empirically.

1. Design Type of Forecast. Figure 21 shows three synthesized hydrographs superimposed on the actual measured hydrograph of St. Louis Creek (shown as solid line A) for the 1949 snowmelt season. The synthesized hydrographs were forecast by use of the 1949 meteorological data and the relationships derived from the 1948 season. The dashed-line hydrograph B was synthesized as follows: Light's equation, Figure 11, was used with the basin coefficient $K = 0.890$, to estimate the total volume of snowmelt contribution for each day. Using these values and the pertinent line on Figure 12, the volume for the first day was derived. Using Figures 14 and 16, the height to peak and the height to trough above the recession line of the preceding day were derived for the day being forecast.

To begin with, the standard recession curve was drawn from the trough of May 23, 1949. Height to peak was plotted above this recession line at 10:00 p.m. and height to trough was plotted above this recession line at noon on May 24th. From the forecasted trough on May 24, another recession line was drawn and peak and trough values were plotted for the following day. This procedure was continued to the trough on May 28. Because of lack of meteorological data for the period May 28 to May 31, inclusive, no forecast could be made for those

days. The forecasted hydrograph was started again at noon on June 1 at approximately the same departure from the measured hydrograph as occurred on noon of May 28. Daily peaks and troughs were forecasted to noon on June 11. The synthesis was started again on June 15, with about the same departure as occurred on June 11.

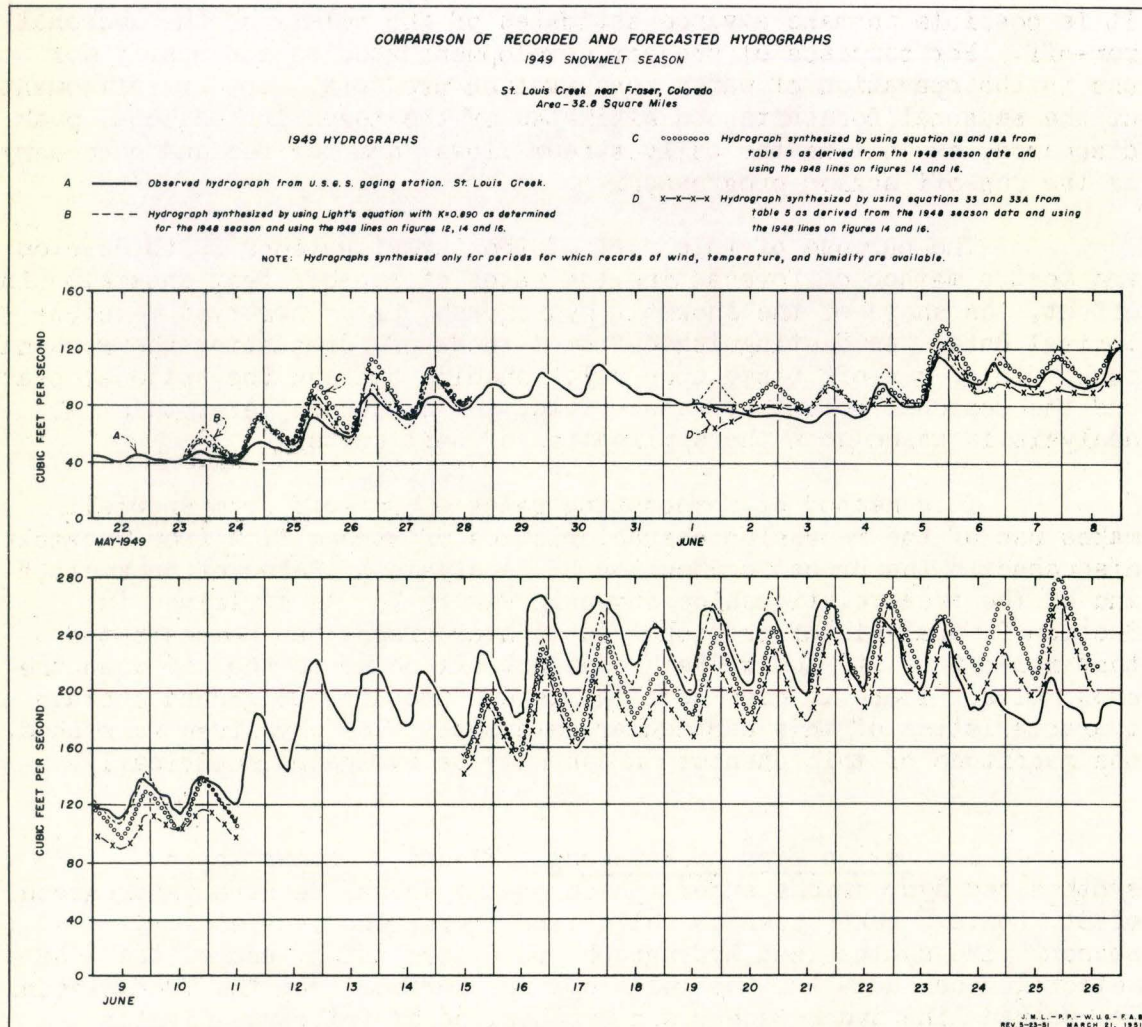


FIGURE 21. Comparison of recorded and forecasted hydrographs.

It is not necessary in this method of forecasting rates of run-off from snowmelt to resort to a graphical delineation of the standard recession curve for each day of snowmelt. Instead of using the curve, the point values on the recession line below the daily peaks and troughs can be computed by the use of the recession equation from Figure 8:

$$Q = Q_0 K_r^t$$

in which: Q = Recession discharge at desired time, t , in cfs.

Q_0 = Discharge at trough of preceding day, in cfs.

K_r = Daily recession coefficient, (for example: $K_r = 0.933$ for St. Louis Creek flows above 30 cfs.)

t = Time in days; 10 hours or 10/24 for the peak, and 24 hours or 1 for the trough.

The open-circle-symbol hydrograph, C on Figure 21, was synthesized as follows: Equation 18, Table 5, was used to estimate the total volume of run-off contribution for each day and Equation 18A, Table 5, was used to estimate the first day's volume of run-off above recession for each day. Using the total run-off volume and the 1948 line in Figure 16, the height to trough for each day was estimated. Using these first-day volumes and the 1948 line in Figure 14, the height to peak for each day was estimated. As explained for the dashed-symbol hydrograph, B, the open-circle-symbol hydrograph, C, was then synthesized using daily height to peak and height to trough values and the recession lines starting on May 23 and plotting the values and curves progressively.

The barbed-wire-symbol hydrograph, D on Figure 21, was synthesized in the same manner from volumes estimated from Equations 33 and 33A, Table 5.

It will be noted that no attempt was made to correct the synthesized hydrograph to the observed hydrograph during the entire 34 days. In operational use, however, it would be possible for the forecaster to correct the synthesized trough flows each day to the observed streamflow record and he would be forecasting only one day ahead. This would result in a better fit than is shown on Figure 21.

A comparison of the numerical values of the 1949 forecasted volumes, peaks, and troughs as computed by Light's equation, Equation 18, and Equation 33, is shown in Table 12. Ultimately when the best combination of meteorological elements is found for estimating the volumes, the relation of height to peak and height to trough with the meteorological variables can be used directly without the necessity of estimating the volumes.

TABLE 12. COMPARISON OF ESTIMATED VOLUMES, PEAKS, AND TROUGHS, ST. LOUIS CREEK, 1949.

COMPARISON OF ESTIMATED VOLUMES, PEAKS, AND TROUGHS BASED ON USE OF LIGHT'S EQUATION
AND EQUATIONS 18, 18A, 33, and 33A FOR THE 1949 SEASON IN ST. LOUIS CREEK

Date	Measured from observed hydrograph A *				Synthesized by Method B * using Light's Equation				Synthesized by Method C * using Equations 18 and 18A				Synthesized by Method D * using Equations 33 and 33A			
	Total volume	First day volume	Peak flow 1/	Trough flow 2/	Total volume 3/	First day volume 4/	Peak Flow 1/ 7/	Trough flow 2/ 8/	Total volume 5/	First day volume 6/	Peak flow 1/ 7/	Trough flow 2/ 8/	Total volume 9/	First day volume 10/	Peak flow 1/ 7/	Trough flow 2/ 8/
	Acre-feet	Acre-feet	cfs	cfs	Acre-feet	Acre-feet	cfs	cfs	Acre-feet	Acre-feet	cfs	cfs	Acre-feet	Acre-feet	cfs	cfs
May 23	115	10	45	39	118	31	65	41	269	20	55	45	198	19	54	43
24	197	17	52	46	269	40	74	47	367	31	71	54	292	32	69	50
25	347	31	70	56	234	38	79	52	323	51	96	61	378	44	86	59
26	458	40	87	69	456	50	94	63	467	63	113	71	461	55	105	69
27	291	22	84	75	455	50	105	73	468	37	101	81	382	44	105	77
June 1	-67	0	80	72	19	25	97	75	-70	-10	75	80	-84	-20	62	75
2	-1	3	74	67	52	27	96	73	-62	18	93	74	104	6	78	75
3	202	14	75	70	175	34	100	74	251	24	93	78	218	21	91	77
4	327	30	94	77	260	39	106	78	246	18	91	81	120	8	82	77
5	595	47	113	93	507	53	122	88	597	64	134	94	472	57	124	86
6	178	16	109	93	213	36	117	90	257	21	109	96	151	12	94	86
7	121	11	102	91	291	41	123	93	138	23	113	95	116	7	90	85
8	664	36	118	109	304	42	127	97	220	30	118	96	202	19	99	87
9	357	42	137.5	113	344	44	132	102	314	40	128	100	296	32	112	91
10	418	39	140	120	383	46	139	107	326	47	137	104	304	33	117	95
June 15	789	77	226	181	530	55	196	159	486	57	195	155	504	61	189	147
16	1281	126	265	211	1205	94	235	183	775	91	229	167	711	90	220	158
17	637	83	265	217	1096	87	253	203	775	86	237	179	610	76	219	166
18	-230	30	244	193	563	57	246	206	475	47	214	182	339	38	194	166
19	607	87	256	199	776	69	260	215	625	72	239	188	547	67	219	171
20	356	72	253	196	765	68	268	224	633	69	243	195	582	72	228	177
21	527	84	262	199					602	82	260	200	641	80	241	185
22	434	68	250	199					770	85	268	209	719	91	258	194
23	7	52	250	184					572	56	252	213	418	49	231	194
24	105	14	196	175					321	63	261	209	382	44	227	194
25	356	36	208	175					616	89	279	214	680	85	261	200

* Please refer to legend of Figure 21.

- 1/ Peak flow occurring at approximately 10:00 p.m. on date listed.
- 2/ Trough flow occurring at approximately noon of the next day.
- 3/ Total volume computed from Light's Equation using basin coefficient derived from 1948 data.
- 4/ First day volume computed from Figure 12 using the line through the 1948 points only.
- 5/ Total volume computed from Equation 18 (Table 5) which was derived from 1948 data.

- 6/ First day volume computed from Equation 18A (Table 5) which was derived from 1948 data.
- 7/ Peak flow computed from Figure 14 using the line through the 1948 points only.
- 8/ Trough flow computed from Figure 16 using the line through the 1948 points only.
- 9/ Total volume computed from Equation 33 (Table 5) which was derived from 1948 data.
- 10/ First day volume computed from Equation 33A (Table 5) which was derived from 1948 data.

2. Operational Type of Forecast. An operational type of day-by-day forecast of peak and trough flows was computed for 1949, using relationships derived from the data for the 1948 snowmelt season. The height to peak and height to trough for each day were derived as previously described for Figure 21. However, in this day-by-day forecast, the start of the forecasted hydrograph was taken to be the observed trough of the preceding day, on the assumption that the preceding day's trough discharge would be known at the time the forecast was being computed. In this approach to an operational forecast, the more generally available single indices, such as degree-days and maximum temperatures were used.

This operational forecast is shown in Figure 22. Line A is the actual hydrograph of the 1949 snowmelt season. Line E designates the daily peaks and troughs forecasted by using degree-days above 32°F as computed from hourly temperatures from a thermograph record, on the assumption for the purpose of this comparison, that such information would be available at the time the forecast was being computed. Line F designates daily peaks and troughs forecasted on the basis of the daily maximum temperature as derived from the thermograph trace. Maximum temperatures from the recorder charts were used, as daily maximum thermometer readings are not available for the 1949 snowmelt season. The use of the daily maximum temperature makes it possible to forecast the peak rate of run-off which occurs on St. Louis Creek about 10:00 p.m. on the day of the observation, and the trough rate of run-off, which occurs at about noon on the following day.

A reasonable degree of agreement is shown between each of the two operational forecasts based upon single index factors and the observed hydrograph. Better agreement exists between actual run-off and day-by-day forecasts based upon additional meteorological data than that shown for the single indices used in Figure 22. The greatest discrepancies between actual and forecasted flows are shown for June 11 and 12, 1949, on which air temperatures remained throughout above 32°F at the Headquarters Station. The effect upon the hydrograph recession relationships of snowmelt continuing throughout a 24-hour period will require further investigation.

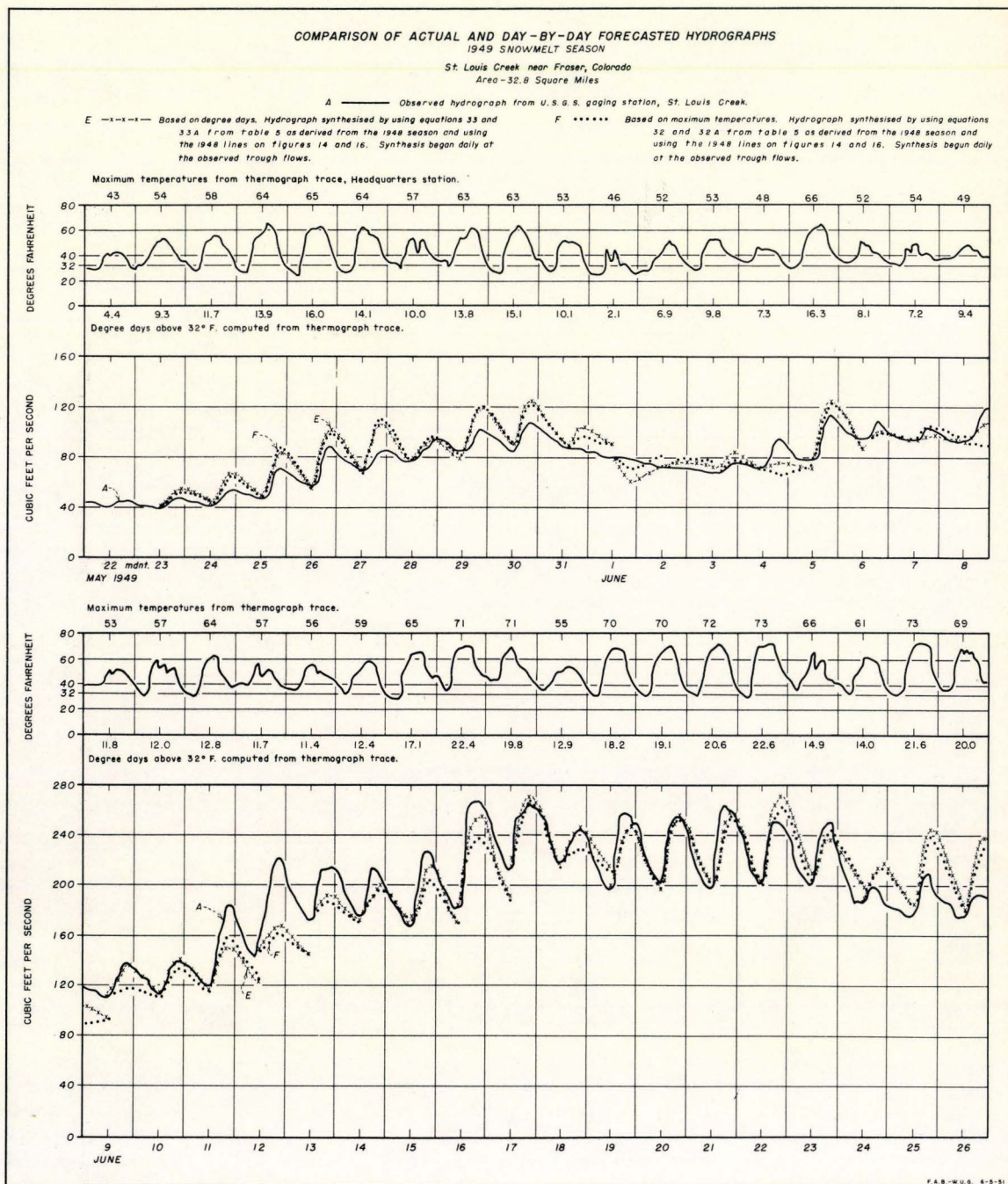


FIGURE 22. Comparison of actual and day-by-day forecasted hydrographs.

G. INSTRUMENTATION .

1. Location of Instruments in the Forest. Instrumentation of the Fraser Experimental Forest for these cooperative investigations is limited to the number, type, and installation that would be practical to use in an operating basin. The map on the frontispiece shows the areal distribution of the stations, while elements observed at each station, type of instruments used, and years of record are summarized in Table 13.

INSTRUMENTATION OF THE BUREAU OF RECLAMATION--FOREST SERVICE COOPERATIVE SNOW INVESTIGATIONS

Element	Instrument	Location ^{1/}	Year ^{2/}
Air temperature	Max.-min. thermometers	Hdqtrs. W. St. Louis Station	1943 to 1944 1946 to 1949 1948 to 1949
	Thermograph ^{3/}	Hdqtrs. W. St. Louis Station Fool Creek Gaging Station E. St. Louis Gaging Station	1944 to 1949 1948 to 1949 1949 1947
Relative humidity	Psychrometer (crank-type)	Hdqtrs. W. St. Louis Station	1949 1948 to 1949
	Hygograph ^{3/}	Hdqtrs. W. St. Louis Station Fool Creek Gaging Station	1947 to 1949 1948 to 1949 1949
Wind travel	Anemometer with operations recorder	W. St. Louis Station in open Height: 47.4 ft above ground 23.1 ft above ground 1.4 ft above snow surface W. St. Louis Station in forest Height: 52.8 ft above ground 24.9 ft above ground 1.4 ft above snow	 1948 to 1949 1948 to 1949 1948 to 1949 1949 1948 to 1949 1948 to 1949
Wind direction	Wind Vane	W. St. Louis Station in open Height: 50 ft	 1949
Precipitation (seasonal) ^{4/}	Sacramento-type storage gage	St. Louis Pass Iron Creek Range Creek E. St. Louis Gaging Station Upper W. St. Louis	1947 to 1949 1947 to 1949 1947 to 1949 1947 to 1949 1947 to 1949

Element	Instrument	Location ^{1/}	Year ^{2/}
Precipitation (weekly)	W. B. Type 8" can	E. St. Louis Gaging Station W. St. Louis Station Fool Creek Basin (15 gages)	1943 to 1949 ^{5/} 1949 1942 to 1949 ^{5/} 1941 to 1949 ^{5/}
Precipitation	Recording gage	Fool Creek Basin E. St. Louis Gaging Station	1941 to 1949 ^{6/} 1943 to 1949 ^{6/}
Stream flow	Water stage recorder	St. Louis Creek (operated by USGS and Colo. State Engr.) Fool Creek (operated by Forest Service) E. St. Louis Creek (operated by Forest Service)	1935 to 1949 ^{7/} 1940 to 1949 ^{8/} 1943 to 1949
Snow water	Snow Tube	Measurements at all storage gages Snow course in Fool Creek Drainage (100 stations) Lapland, Colo. No. 70 surveyed by U.S. Soil Conservation Service Snow course in East St. Louis Creek Drainage (63 stations)	1947 to 1949 1940 to 1949 1938 to 1949 1943 to 1949
Solar radiation	Pyrheliometer with recording potentiometer	Shadow Mountain Government Camp near Grand Lake, Colorado	1948 to 1949
Soil moisture	Shovel, scales, and oven	King Creek Lower St. Louis	1942 to 1944 1947 to 1949
Ground water	3 wells read weekly 1 well with recorder	Fool Creek Basin Fool Creek Basin	1941 to 1949 ^{6/} 1941 to 1949 ^{6/}

^{1/} Except for the solar radiation installation, all stations are in the Fraser Experimental Forest, Colorado.

^{2/} Approximately April 1 to end of Forest Service field season only, except for Storage Precipitation Gages and solar radiation station, which operate continuously.

^{3/} Thermograph and Hygograph are combined in one instrument, the Hygrothermograph.

^{4/} Also monthly, during Spring.

^{5/} Spring snowmelt period only.

^{6/} Summers only.

^{7/} Recorded all year.

^{8/} Recorded all year 1940-1941.

TABLE 13. Instrumentation of the Bureau of Reclamation-Forest Service Cooperative Snow Investigations.

Because of lack of power supply at the Forest Headquarters, the solar radiation recorder is operated at the Bureau of Reclamation's Shadow Mountain Government Camp approximately 21 miles due north.

The greatest concentration of instruments is at the West St. Louis Station, as shown on Figure 23. Here are two 45-foot wind towers, one in a large open meadow and the other in the forest, with anemometers mounted at the top, middle, and near the base of each. Wind velocities from the six anemometers and wind direction at the top of the tower in the open are recorded by an electrical operations recorder. A weather shelter near the tower in the open contains a hygrothermograph, crank-type psychrometer, and maximum and minimum thermometers. Three shielded 8-inch precipitation gages are installed in the open area where weekly snow samples are also taken.

At the Headquarters Station (Figure 24), an anemometer, hygrothermograph, psychrometer, and maximum and minimum thermometers are operated for comparison and to provide continuity of record when any of the instruments at the West St. Louis Station are out of operation. In addition, daily readings of an 8-inch precipitation gage are recorded. Hygrothermograph, psychrometer, and maximum and minimum thermometers are also installed near the Fool Creek stream gage.



FIGURE 23. West St. Louis Station, April 7, 1950.

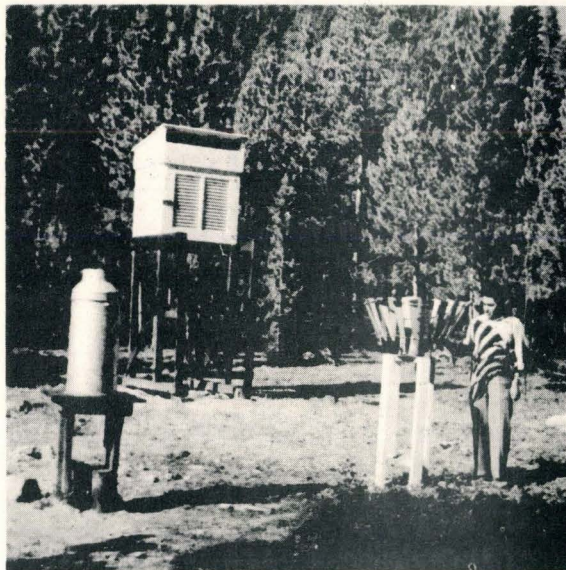


FIGURE 24. Headquarters Station, August 1, 1950.

Sacramento-type seasonal storage precipitation gages are established at five locations within the basin as shown on the frontispiece map. Snow measurements are made in the vicinity of each gage when they are visited on April 1, May 1, and June 1, of each year.

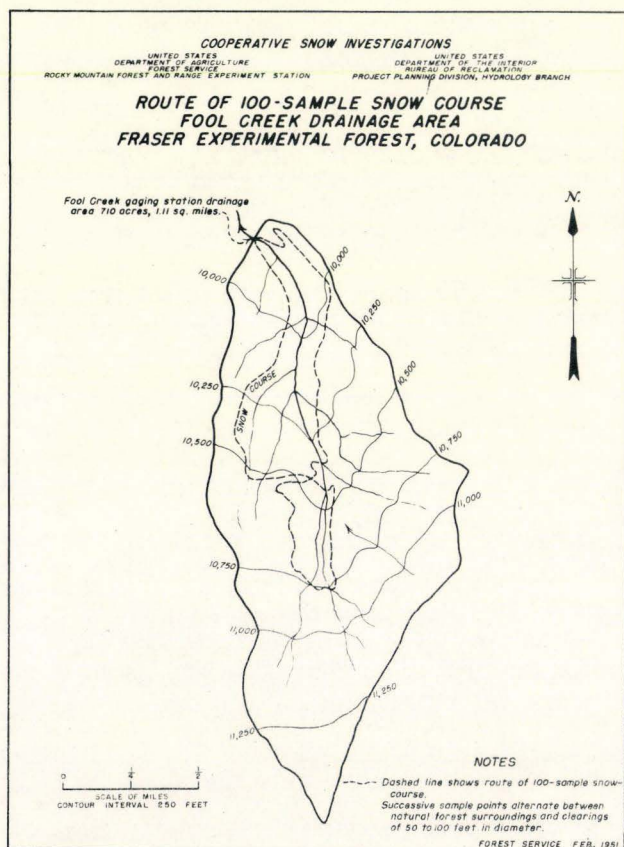


FIGURE 25. Snow course in Fool Creek area.

from 50 to 100 feet in diameter were made surrounding each gage. Subsequently the gages were read weekly during the snowmelt seasons as well as during the summers.

One recording precipitation gage was installed near the Fool Creek stream gage and was in operation during the summers from 1941 to 1949 inclusive.

In the East St. Louis Creek basin, the Forest Service established a 63-point snow course with the points in natural openings at about 200-foot intervals. The course was measured at the start of the snowmelt season each year from 1943 to 1949 inclusive. An 8-inch non-recording rain gage near the East St. Louis Creek stream gage was read weekly during the snowmelt season during these same years. One recording gage at the same location was operated during the summers also from 1943 to 1949 inclusive.

Streamflow from the entire St. Louis Creek drainage basin is measured at the station operated jointly by the Geological Survey and

In the fall of 1939, a snow course approximately 3-1/2 miles in length was located in the Fool Creek watershed as is shown in Figure 25. One hundred snow-sampling points were located at regular intervals along this course. Snow measurements were made at these points on April 1 and weekly or biweekly until the disappearance of snow. Early in 1940 clearings ranging from 50 to 100 feet in diameter were made at every other snow sampling point, so that 50 snow samples are from cleared areas and 50 from undisturbed forest areas.

During the summer of 1940, 15 standard 8-inch non-recording rain gages were placed at equal intervals along the Fool Creek snow course. Readings were made semiweekly during the summers of 1940 and 1941. In early spring, 1942, clearings ranging

the Colorado State Engineer. In addition, the Forest Service operates stream gages on Fool Creek and East St. Louis Creek.

A study of evaporation from snow was performed by the Forest Service during the 1940, 1941, and 1942 snowmelt periods. The special installation and discussion of results were reported by Wilm and Dunford (31), and Wilm and Connaughton (29).

A detailed description of each type of installation, together with a discussion of instrument characteristics and operation problems where pertinent, is described in the following subparagraphs of this section.

2. Solar Radiation Measurements. The solar radiation station at Shadow Mountain Camp near Grand Lake, Colorado, consists of an Eppley ten-junction pyr heliometer mounted on top of a quonset-type building (about 25 feet above ground) and a Micromax recording potentiometer within the building. A record of solar and sky radiation incident upon a horizontal surface is obtained.

a. Pyrheliometer

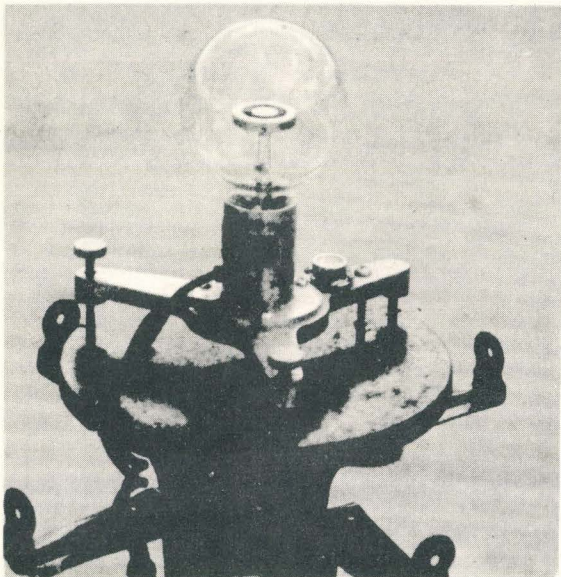


FIGURE 26. Pyr heliometer affixed to mount, June 8, 1948.

The differential in temperature between the two rings when radiation falls upon them creates an electromotive force that is closely proportional to the amount of radiation received. The rings are mounted horizontally in the center of a thin spherical glass bulb which is sealed to

(1) Description.--

The pyr heliometer, as shown on its mounting in Figure 26, is an Eppley ten-junction pyr heliometer of the type used by the Weather Bureau, United States Department of Commerce. The instrument consists of two concentric rings of equal area, one coated with platinum black or carbon lampblack and the other coated with magnesium white. Hot junctions of a multiple-couple thermopile of gold-palladium and platinum-rhodium alloys are mechanically attached to, but electrically insulated from, the under side of the black rings, and the cold junctions are similarly fastened to the under side of the white ring. The

prevent deterioration and also to prevent moisture from condensing within (16, pp. 8-9). Specifications required the instrument to have an output of between 1.5 and 2.0 millivolts per langley (1) per minute^{1/}; a responsiveness of fifty-five seconds or less to develop maximum output due to a change of radiation from zero to one langley per minute; and a resistance of between 35 and 45 ohms. It should be sensitive to radiation of wave lengths between 0.295 and 2.5 microns (μ)^{2/} (16, p. 8). The lower limit is the limit of solar spectrum in the ultra-violet due to atmospheric absorption and the upper limit is the cut-off by the glass cover which is practically opaque for wave lengths greater than 2.5 μ (16, p. 3).

The bulk of the radiation originating at the sun is between wave lengths 0.15 and 4 μ (7), and the principal components of the radiation reaching the earth are:

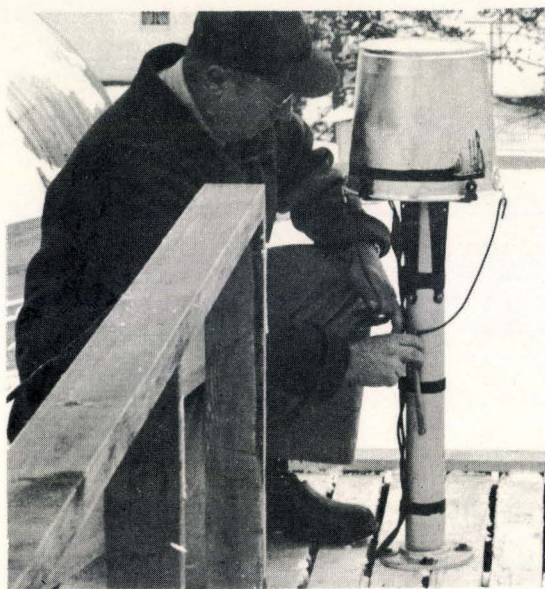
Ultra-violet, 0.29 to 0.4 μ , 4 percent of total

Visible, 0.4 to 0.7 μ , 43 percent of total

Infra-red, longer than 0.7 μ , 53 percent of total.

The percentages given are approximate since the position of the maximum of the solar energy curve varies with increasing air mass (length of the path through a homogeneous atmosphere over which the same attenuation would be produced as takes place in the actual path of the solar beam) (16, p. 3).

(2) Auxiliary Equipment.--During hailstorms a galvanized metal pail is placed over the pyrhelimeter to protect it from damage. Figure 27 shows the pail in position over the pyrhelimeter.



1/ 1 langley equals
1 gram calorie
per square
centimeter
1 small or gram
calorie equals
0.0039685
B.T.U.

2/ 1 micron equals
 $\frac{1}{1,000,000}$
meter.

FIGURE 27. Hail-protection bucket in place over pyrhelimeter, October 25, 1947.

b. Recording Potentiometer

(1) Description.--The electromotive force (emf) produced by the pyrhelimeter is recorded on the strip chart of a Leeds and Northrup Micromax Recording Potentiometer, Model S, Number 40101-S, single point pen, curve tracing with 0 to 4 millivolt range (19, pp. 32-39). It has a chart speed of 1-35/64 inches per hour, with automatic current standardizer. Full scale range of the recorder chart is 4 millivolts or 2 langleys per minute.

The Micromax operates to balance the emf of the pyrhelimeter against a standardized emf produced by a dry cell. When these forces are unbalanced, the Micromax automatically moves the slide wire to restore balance, and, as this motion is coupled to the pen, it is recorded on the strip chart. To control the effect of decreasing voltage output of the dry cell, its output is balanced every 48 minutes against a standard cell which is a primary source of a constant emf practically independent of temperature effects. Balance is maintained by automatic adjustment of a rheostat in series with the battery (19, pp. 12-15).

(2) Auxiliary Equipment.--The auxiliary equipment used with the recorder included a heater, time switch, light, and standard cell protector. All but the heater are mounted on a panel board and are designated as (A), (D), (G), and (I), respectively, in Figure 28.

The panel board was specially designed as a unit installation to hold all the instruments and includes a work shelf and storage space.

(3) Heater.--The heater (A) is turned on and off automatically by the thermostat (B), and relay (C), to keep the recorder (E) at nearly constant 70°F temperature. This precaution assures uniform operation of the recorder, longer battery life, and prevents damage to the standard cell that would occur should the equipment be allowed to freeze.

(4) Time Switch.--The clock driven time switch (D) is set to turn the recorder on in the morning and off at night. The self-starting electric clock (F) is not only for the convenience of the operator in making time checks and notations on the chart but also to indicate interruptions in the power supply.

(5) Circuits.--Power for the equipment on the panel is furnished through two circuits protected by circuit breakers (H). One circuit powers the heater, thermostat, and light; while the other has the clock, time switch, and recorder. Separation of the heater and light from the recorder is a precaution against power failure in the recorder circuit due to possible short circuit or overloads in the appliances. The panel light (G) provides illumination for the panel and recorder mechanism.

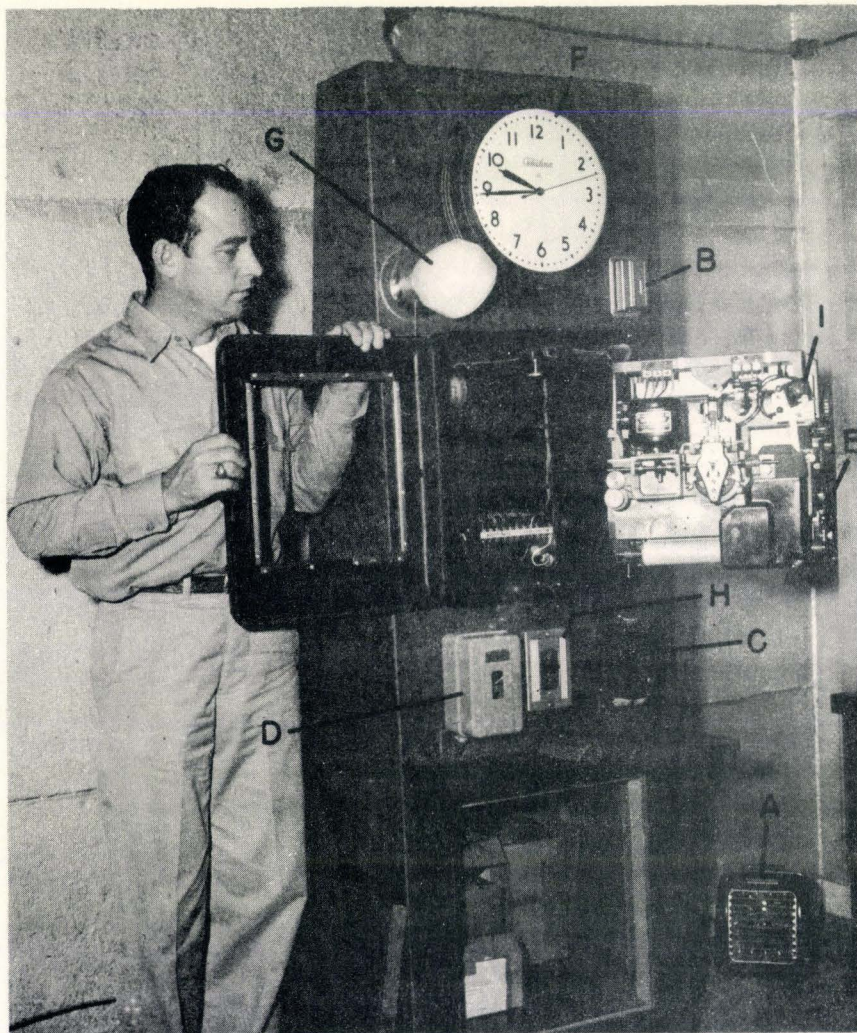


FIGURE 28. Panel board at Shadow Mountain Solar Radiation Station. Heater (A) is controlled by thermostat (B) through the relay (C). Time clock (D) automatically starts and stops the recording potentiometer (E). Electric clock (F). Panel light (G). Circuit breaker (H). Standard cell protector (I). October 25, 1947.

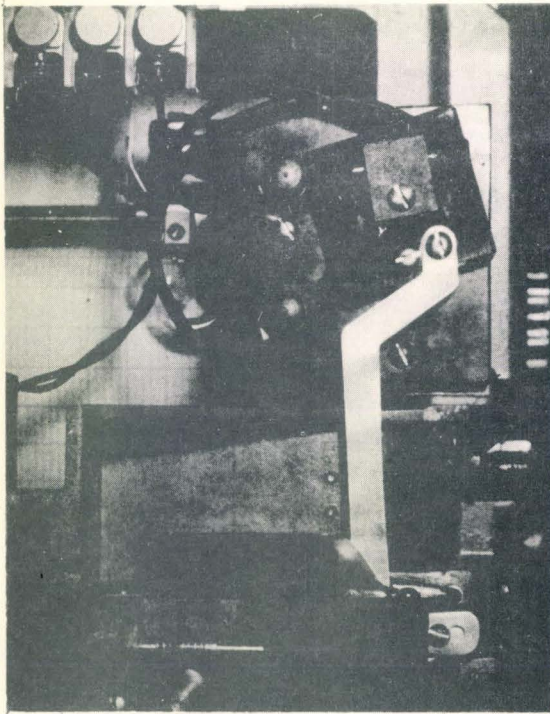


FIGURE 29. Mercury switch standard cell protector, October 25, 1947.

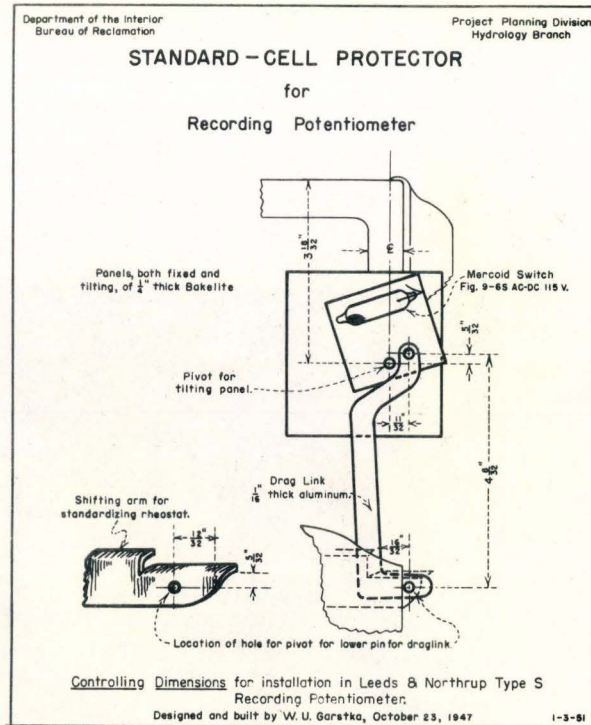


FIGURE 30. Details of standard cell protector.

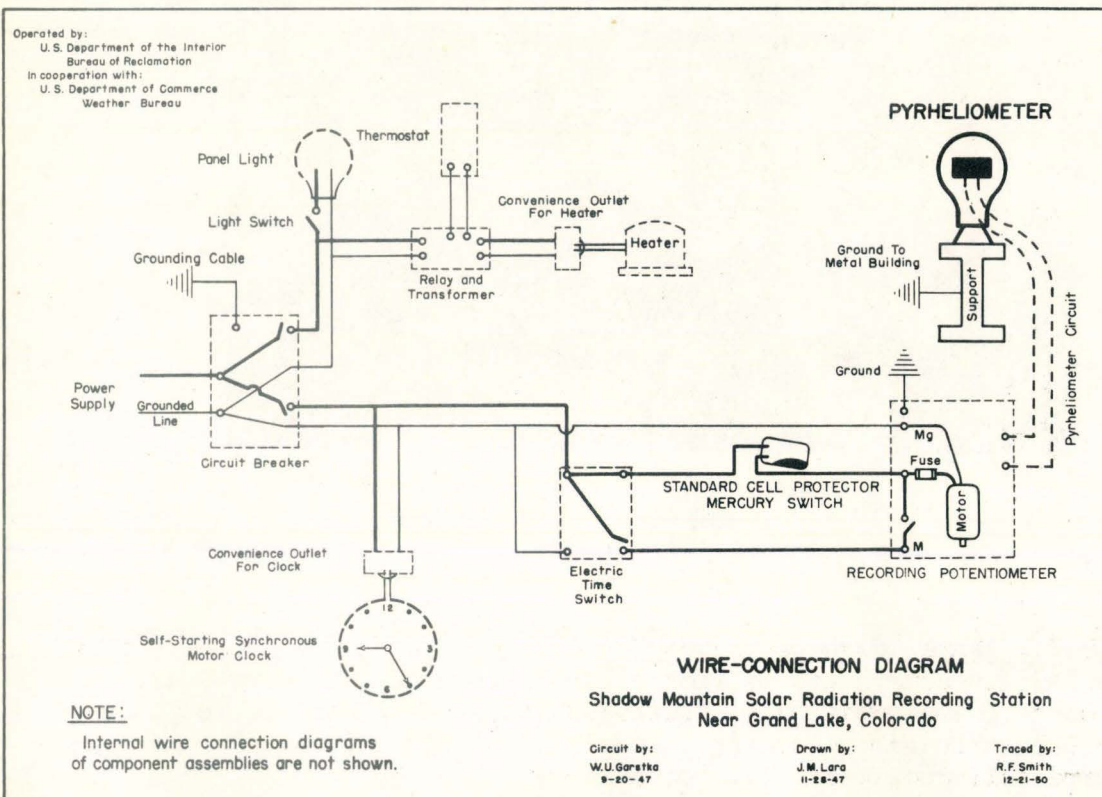


FIGURE 31. Wire connection diagram, Shadow Mountain Solar Radiation Station.

(6) Standard Cell Protector.--There is always the possibility that the standard cell will be in the circuit when the time switch shuts the recorder off, thereby endangering the standard cell by allowing it to discharge continuously or even completely. To prevent this, a mercury switch standard cell protector (I) was designed as pictured in detail in Figure 29. Controlling dimensions of the protector and wire-connection diagram for panel instruments are shown in Figures 30 and 31. The mercury switch is mounted so that when the standard cell is in the circuit, the current bypasses the time switch and the motor switch through the mercury switch. Thus the time switch and motor switch are not effective when the standard cell is in the circuit. As soon as the standard cell is again out of the circuit, the mercury switch opens and the time switch and motor switch again cut into operation.

c. Recorder Chart and Tabulation

(1) Typical Chart.--A typical record of one day's solar radiation is shown in Figure 32. The vertical scale on the recorder chart shows intensity of radiation with the smallest division representing 0.02 langley per minute. The spacing between vertical lines is 20 minutes of time. The time scale added in writing shows Apparent Solar Time. A tabulation of the corrections as of June 1950 to apply to Mountain Standard Time to obtain Apparent Solar Time at this station is given in Table 14.

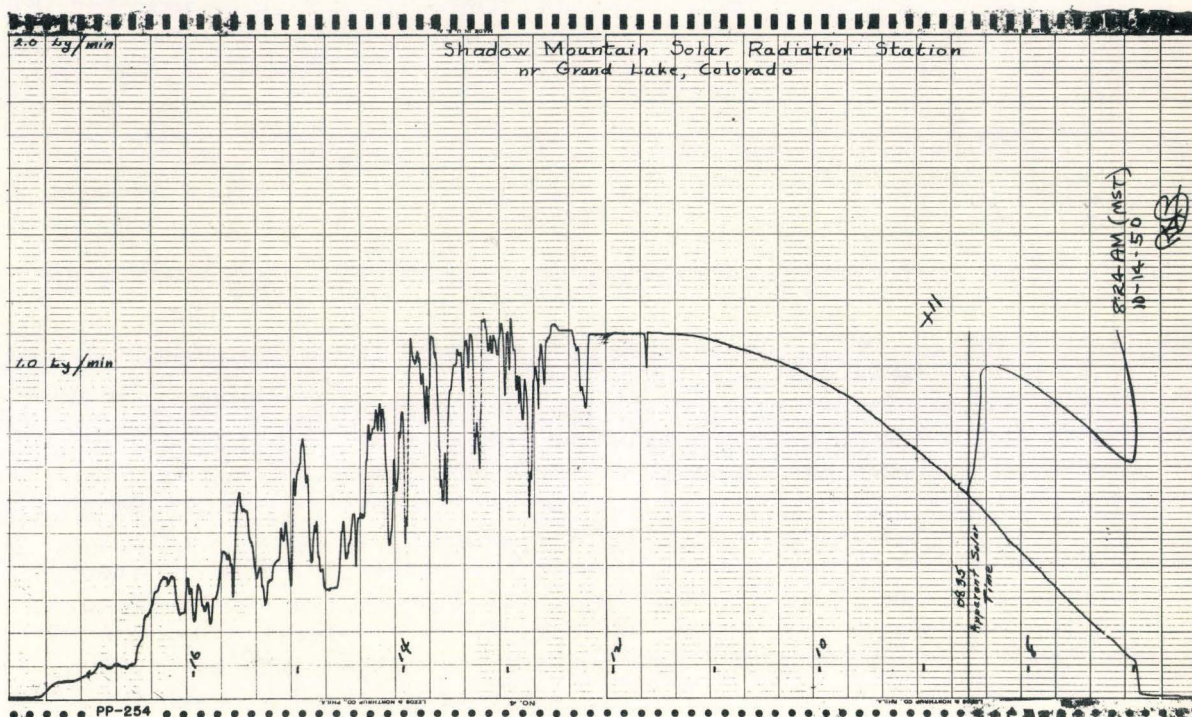


FIGURE 32. Solar radiation record for October 14, 1950.

SOLAR TIME

Shadow Mountain Solar Radiation Station near Grand Lake, Colorado.
Longitude 105° 51' W, Latitude 40° 13' N, Elevation 8417 feet.

<u>Date</u>	<u>Corrections</u>	<u>Date</u>	<u>Corrections</u>	<u>Date</u>	<u>Corrections</u>
Jan. 1-3	- 7	May -6	0	Oct. -1	+ 7
4-5	- 8	7-21	+ 1	2-5	+ 8
6-7	- 9	22-31	0	6-8	+ 9
8-9	-10	1-6	- 1	9-12	+10
10-12	-11	7-11	- 2	13-16	+11
13-15	-12	12-16	- 3	17-22	+12
16-18	-13	17-20	- 4	23-	+13
19-21	-14	21-25	- 5	Nov. -14	+13
22-25	-15	26-30	- 6	15-19	+12
26-30	-16	July 1-5	- 7	20-23	+11
Feb. 31-	-17	6-12	- 8	24-26	+10
-23	-17	13-	- 9	27-29	+ 9
24-28	-16	Aug. -8	- 9	30-	+ 8
Mar. 1-5	-15	9-14	- 8	Dec. -2	+ 8
6-9	-14	15-19	- 7	3-4	+ 7
10-13	-13	20-23	- 6	5-7	+ 6
14-17	-12	24-27	- 5	8-9	+ 5
18-20	-11	28-30	- 4	10-11	+ 4
21-23	-10	31-	- 3	12-13	+ 3
24-27	- 9	Sep. -2	- 3	14-15	+ 2
28-30	- 8	3-5	- 2	16-17	+ 1
31-	- 7	6-8	- 1	18-19	0
Apr. -2	- 7	9-11	0	20-21	- 1
3-6	- 6	12-14	+ 1	22-23	- 2
7-9	- 5	15-17	+ 2	24-25	- 3
10-13	- 4	18-20	+ 3	26-27	- 4
14-17	- 3	21-22	+ 4	28-30	- 5
18-22	- 2	23-25	+ 5	31-	- 6
23-27	- 1	26-28	+ 6		
28-	0	29-	+ 7		

Calculated by Solar Radiation Supervisory Station, United States Weather Bureau, Boston 9, Massachusetts, and transmitted as enclosure to letter dated June 8, 1950, to R. K. Borens, Shadow Mountain Camp, Grand Lake, Colorado.

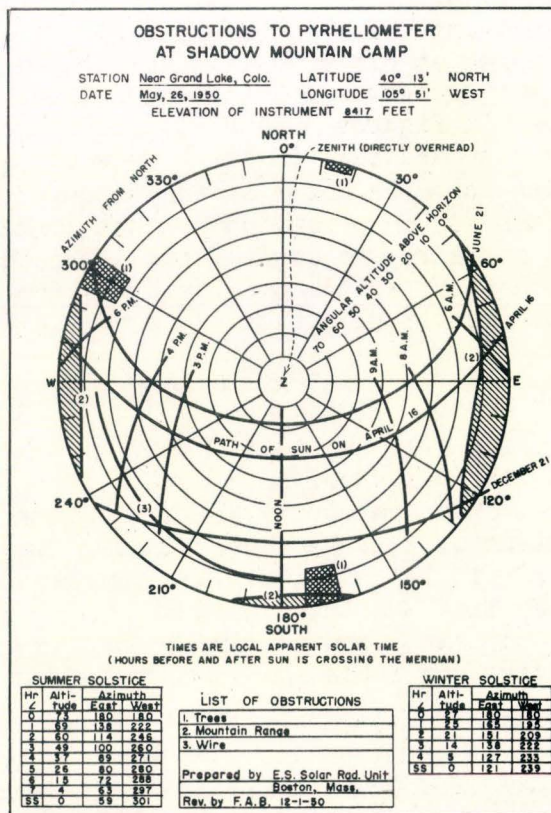


TABLE 14. Corrections to apply to Mountain Standard Time to obtain Solar Time.

FIGURE 33. Obstructions to
pyrheliometer at Shadow Mountain
Camp.

(2) Obstructions.--The sharp rise on the chart for October 14, 1950, in Figure 32 at approximately 7:00 a.m. Apparent Solar Time occurs when the sun emerges from behind the mountains in the east. Figure 33 shows graphically all the permanent obstructions for this location. The mountains to the east, the telephone wires to the southwest, and the mountains and trees to the west all cut off some of the radiation. Clouds cut off much of the radiation and on heavily overcast days, the intensity of radiation received by the pyrheliometer is very low. When broken clouds pass over, the record shows a series of sharp vertical dips as in the afternoon of October 14, 1950. Often, between the dips caused by the obstruction of clouds, the record trace will be abnormally high due to the added radiation reflected from the nearby clouds. Notes are placed on the tabulation when this is obvious, but no attempt has been made to correct the charts for such conditions.

(3) Frost.--Frost on the pyrheliometer bulb will cause erroneous readings. Usually the trace will be high due to the refractiveness of the frost crystals concentrating radiation to the

sensitive rings. The rays that are transmitted directly to the rings are reduced in intensity but the additional rays that are refracted onto the rings make the net radiation on the rings too high. Usually the observers clean the frost off as soon as it is noticed and the trace drops abruptly. If the frost is allowed to remain until it melts off, the trace has a prominent peak as is shown on the traces for November 5 and 6, 1949 in Figure 34. Observations made later show

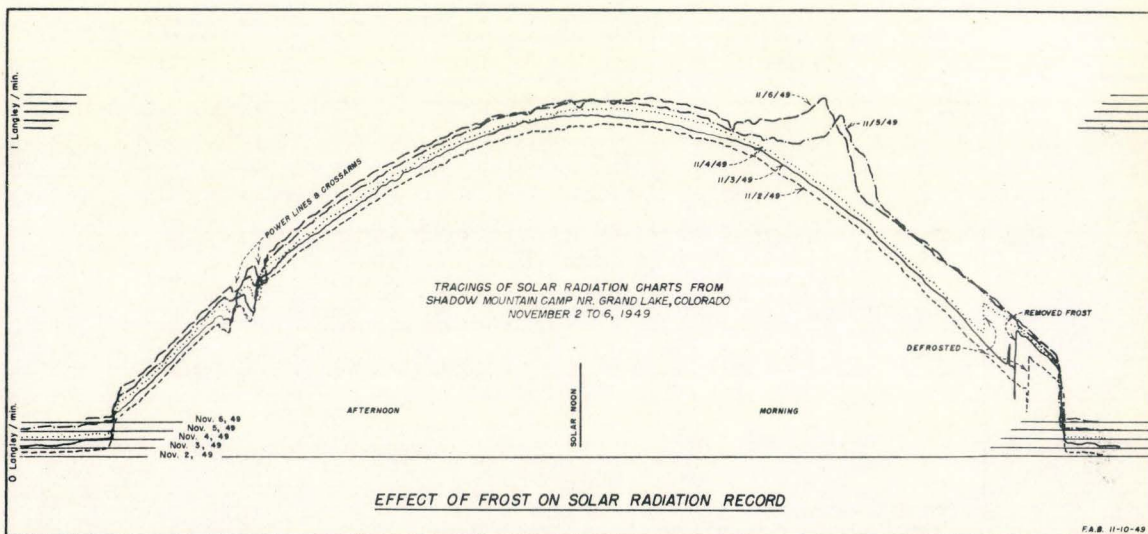


FIGURE 34. Effect of frost on solar radiation record.

that the trace starts to rise as the frost melts off the bulb on the side toward the sun. Apparently, this allows the direct rays to reach the rings as well as reflections from the frost on the side of the bulb away from the sun. After the peak, the trace starts to fall back to normal values as the frost melts from the side away from the sun. When the frost effect is noticeable, a correction is applied to the recorder chart before the values are tabulated. The correction is applied by tracing a chart for a clear day without frost onto the frost-effected chart and tabulating the readings of this lower trace.

(4) Transcription.--Tabulations are made of hourly totals of radiation and daily totals with weekly means on the WB Form 1091 (HD-33) as shown in Table 15. Two auxiliary templates, a time scale and a grid overlay, used by the tabulator, were developed by the Processing and Analysis Unit, of the Corps of Engineers-Weather Bureau Cooperative Snow Investigations, Oakland, California (11). In use, the time scale is shifted to agree with the time notations on the chart in standard time. Comparison of starting and stopping time, and intermediate time checks with the time scale will show up any stoppages or erratic clock actions, and appropriate corrections, if needed, are made. Table 14 is then referred to and adjustment is made to convert

WB FORM 1081 (HO-33)																			
Solar and sky radiation measured at Shadow Mountain Solar Radiation Station near _____ from June 4, 1950 _____ to July 1, 1950 _____																			
Radiation in gr.-cal. per cm. ² of horizontal surface during hour ending (apparent time)																			
DATE	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	DAILY TOTAL		
	Gr.-cal.	Gr.-cal.	Gr.-cal.	Gr.-cal.	Gr.-cal.	Gr.-cal.	Gr.-cal.	Gr.-cal.	Gr.-cal.	Gr.-cal.	Gr.-cal.	Gr.-cal.	Gr.-cal.	Gr.-cal.	Gr.-cal.	Gr.-cal.	Gr.-cal.	Gr.-cal.	
June 4	0.1	3.0	9.8	11.7	30.4	72.4	94.2	97.8	97.8	93.4	54.9	63.4	48.8	30.1	6.9	0	714.7		
5	0.1	8.7	29.0	49.0	67.0	80.5	90.5	95.5	94.4	88.0	78.0	62.9	45.7	21.7	8.9	0.2	820.1		
6	0.1	9.2	29.5	50.2	68.3	81.7	92.4	98.7	96.2	91.1	81.1	26.6	24.6	8.1	1.9	0	759.7		
7	0	9.0	29.9	50.0	68.0	81.5	93.1	98.5	91.4	88.7	41.1	40.0	37.4	22.5	8.4	0.6	760.1		
8	0.1	10.2	31.0	51.2	70.6	90.0	95.7	169.8	94.6	83.1	80.8	64.0	47.2	23.1	8.3	0.5	820.2		
9	0.1	9.7	30.5	50.7	69.0	83.0	92.5	96.8	95.3	89.5	77.5	65.0	47.2	29.1	12.1	0.7	848.7		
10	0.2	11.8	31.2	50.4	68.6	81.6	91.6	95.8	94.6	89.0	80.6	66.4	44.7	24.5	11.9	1.0	843.9		
Mean	0.1	8.8	27.3	44.7	63.1	81.5	92.9	93.3	94.9	89.0	70.6	55.5	42.2	22.7	8.3	0.4	795.3		
June 11	0.2	9.9	30.0	50.7	69.2	81.2	90.9	95.7	94.8	87.5	79.0	51.8	45.6	28.0	10.5	0.2	825.2		
12	0.1	9.1	29.5	50.0	69.6	82.8	92.2	96.5	95.7	89.0	78.8	64.3	47.0	28.0	10.2	1.3	844.1		
13	0.6	11.7	31.0	50.8	68.0	80.0	90.8	95.7	94.8	73.1	64.1	52.6	34.4	27.5	14.7	1.7	791.5		
14	0.6	11.3	31.1	51.0	69.1	81.5	90.7	95.4	94.8	88.5	80.0	66.0	49.2	31.2	14.2	2.0	856.6		
15	0.3	12.5	31.1	50.2	68.0	79.8	90.1	94.4	93.5	89.4	80.9	72.2	18.0	9.3	5.4	1.5	796.6		
16	0.4	10.6	29.3	48.7	65.0	79.5	85.0	75.3	93.1	58.5	74.7	58.7	29.4	27.2	7.8	1.3	744.5		
17	0.6	10.7	30.3	50.5	68.1	80.5	90.9	94.8	96.1	84.8	79.0	65.5	49.3	30.0	13.1	1.3	845.5		
Mean	0.4	10.8	30.3	50.3	68.1	80.8	90.1	92.5	94.7	81.5	76.6	61.6	39.0	25.9	10.8	1.3	814.7		
June 18	0.6	13.3	33.0	52.2	69.3	82.3	91.5	96.4	98.6	84.5	69.6	47.4	40.5	19.8	8.3	1.2	808.5		
19	0.6	10.8	31.5	48.2	65.2	72.7	85.3	87.9	63.1	22.2	15.4	6.6	27.0	8.7	0.7	0.4	533.8		
20	0.1	8.6	28.0	49.3	63.8	84.5	69.2	60.9	106.0	87.0	60.0	72.9	23.9	10.0	9.5	1.3	735.0		
21	0.2	11.4	29.4	48.4	65.1	78.8	71.8	83.4	31.5	12.5	13.2	20.0	45.3	28.0	11.3	0.9	551.2		
22	0.1	2.9	23.5	45.0	44.6	42.9	31.8	75.3	65.2	53.2	54.5	28.3	19.1	21.5	12.7	0.8	521.4		
23	0.5	11.9	22.4	29.0	65.9	79.1	94.2	90.3	95.0	85.5	76.3	58.9	45.9	27.8	12.1	0.9	795.7		
24	0.2	9.2	29.0	48.3	65.6	79.8	89.2	94.5	93.5	89.2	32.7	25.8	11.1	27.9	11.7	0.3	708.0		
Mean	0.3	9.7	28.1	45.8	61.0	74.3	76.1	84.1	79.0	62.0	46.0	37.1	30.4	20.5	9.5	0.8	664.7		
June 25	0.2	7.7	28.5	48.4	67.0	81.2	90.3	94.3	95.9	88.0	77.0	63.0	45.3	26.8	9.4	0.3	821.3		
26	0.3	11.8	30.5	50.4	68.0	80.6	90.0	91.4	95.8	99.0	25.7	24.4	22.2	30.1	6.9	0.8	707.9		
27	0.3	9.5	29.0	48.0	65.6	79.1	90.6	97.8	81.0	33.0	20.5	18.9	17.9	17.8	6.6	0.6	616.2		
28	0.2	9.6	29.2	48.0	65.1	78.6	78.8	77.7	21.2	20.7	25.7	33.0	16.0	30.4	15.9	2.4	552.5		
29	0.4	9.5	26.8	47.5	60.2	55.0	65.5	77.4	92.0	88.8	73.3	65.0	28.8	27.6	9.9	0.7	728.4		
30	0.3	12.0	24.4	48.9	64.7	84.7	74.5	71.5	68.5	65.6	56.2	59.0	46.3	27.8	10.5	0.5	715.4		
July 1	0.1	5.7	21.3	49.8	52.9	79.4	67.9	86.1	61.8	57.3	49.2	53.5	29.3	12.2	5.5	0.8	632.8		
Mean	0.2	9.4	27.1	48.7	63.4	76.9	79.6	85.2	73.5	61.8	46.8	45.3	29.4	24.7	9.2	0.9	682.1		
¹ Partly interpolated. ² OPERATED BY THE BUREAU OF RECLAMATION IN COOPERATION WITH WEATHER BUREAU ³ Intensities greater than 2.1 cal./sq cm./min. caused by reflection from clouds.																			
Prepared by <u>F. A. Bartle</u>										<u>F. A. Bartle</u>									

TABLE 15. Tabulation of solar radiation for June 4, 1950 to July 1, 1950 at Shadow Mountain Camp.

to Apparent Solar Time. Marks are made on the chart to indicate each hour. The overlay is a transparent grid covering two hours, which is divided into 10-minute intervals by vertical lines. One hour has horizontal lines spaced to provide a scale of langleys per 10 minutes. The other hour has horizontal lines to provide a scale of langleys per hour. For smooth portions of the radiation record the langleys per hour scale is placed over the trace between two hour marks, the average ordinate for the hour is estimated by eye, and the scale reading on the overlay for this average ordinate is recorded as the total radiation for that hour. For irregular traces, the langleys per 10 minute scale is used, and ten minute average ordinates are estimated and read from the overlay scale. The six 10-minute values are added to give the total for the hour and this total is checked by using the ly/hr scale.

d. Calibrations

Periodic calibration of both the pyrheliometer and the potentiometer are made by the Weather Bureau Solar Radiation Field Testing Unit, Boston, Massachusetts.

(1) Pyrheliometer.---The station pyrheliometer is calibrated periodically by comparison with a reference pyrheliometer which has been standardized accurately on the Smithsonian Scale of Pyrheliometry. The reference pyrheliometer is mounted alongside the station pyrheliometer and connected to the recorder circuit with an automatic non-thermal switch which alternates circuits every minute. Comparison of the recordings is used to compute the output of the station pyrheliometer. The compressor resistor in the potentiometer is adjusted to convert this output to the proper scale reading of the chart.

(2) Recording Potentiometer.---The observer makes weekly checks and adjustments, if necessary, of the open-circuit mechanical balance of the galvanometer. The recording potentiometer is checked periodically for accuracy of recording by an electronic engineer from the Weather Bureau.

3. Wind Measurements.

a. The Installations

Wind velocities are recorded at two wind towers in the drainage basin of West St. Louis Creek as shown on the frontispiece. The wind tower in the open is shown in Figure 23. Anemometers at the wind tower in the open were installed and have remained at the following elevations of the cups:

Low--1.4 feet above snow or ground surface

Medium--23.1 feet above ground surface below anemometer

High--47.4 feet above ground surface below anemometer



FIGURE 35. Low-level anemometer at wind tower in the open, October 24, 1947.

The low anemometer (Figure 35) mounted on an adjustable bracket, was placed apart from the wind tower and other structures, in order to expose it to wind not modified by impact upon nearby obstructions. In the forest, during the 1948 snowmelt season, two anemometers were installed on brackets affixed to living trees; cups were at the following elevations:

Low--1.4 feet above
snow or forest floor
surface

Medium--22.5 feet above
forest floor surface
below anemometer.

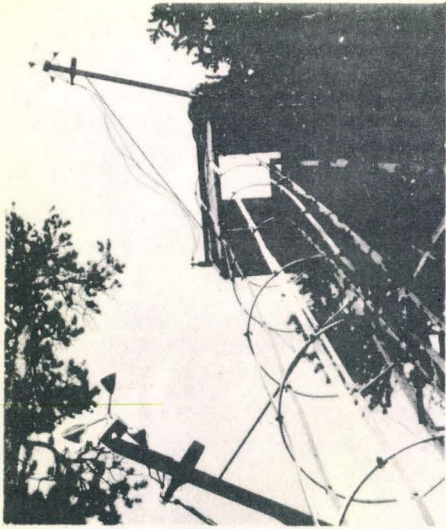


FIGURE 36. Wind tower in forest as seen from below the top anemometer, August 1, 1950.

A steel lookout tower was erected in the forest in preparation for the 1949 snowmelt season (Figure 36). This permitted the use in 1949 of three anemometers, which were installed at the following elevations:

Low--1.4 feet above snow or forest floor surface

Medium--24.9 feet above forest floor surface below anemometer

High--52.8 feet above forest floor surface below anemometer.

b. Anemometer

Wind velocity and total wind increment measurements are made with Friez Model 349 anemometers. Instructions for the installation, operation, and maintenance of this anemometer are given in the manufacturer's bulletin (6). Cup arms and spindles are of stainless steel. The conical cups are of copper. The manufacturer states that tests performed on stock models at the Bureau of Standards wind tunnel showed that this type of anemometer's registration was within one mile per hour of the true velocity throughout the range up to one hundred miles per hour. No corrections were applied, therefore, to the anemometer records.

The anemometers used in this investigation are equipped with the standard 1 mile and 1/60 mile electrical contacts. In addition, total miles of wind passage were registered by each anemometer on an odometer. The mileages of total wind passage, as registered by the odometers for specified periods of time, serve as a check upon the performance of the remote registering wind recorder. The contact points are shown in Figure 37. The anemometers are cleaned and oiled at frequent intervals.

The effectiveness of the closure of the contacts was determined, for all positions of the contact wheel pins and cams, by determining contact circuit resistances with an indicating ohmmeter. The position of the movable contact arm was adjusted to just secure positive closure of the circuit on the shortest contact wheel pin or cam. Thereafter, periodic measurements of the resistance of open and closed circuit anemometer wiring installations in the field were made throughout the periods of record. Any departures from the normal values established for each circuit were investigated and suitable adjustments were made.

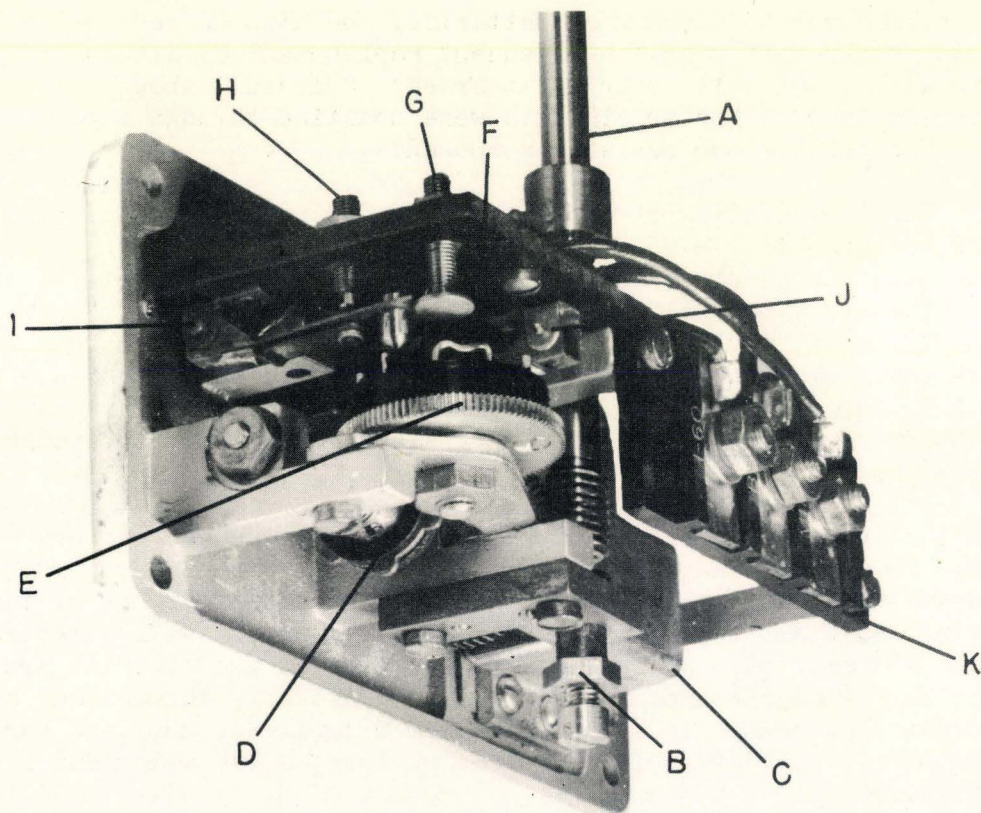


FIGURE 37. Mechanism inside the contact box of a Friez Model No. 349 anemometer. Spindle (A). Spindle thrust bearing (B). Odometer (C). 1/60-mile-contact cams (D). Gear carrying 1-mile-contact cams (E). Two 1-mile cams linked with a bridge to produce long "pips" on recorder charts (F). Movable electrical contact-point stop (G). Fixed electrical contact-point positioning bolt (H). 1-mile-contact-assembly hinge (I). 1/60-mile-contact-assembly hinge (J). Junction block (K). March 14, 1951.

c. Recording of Wind Velocity and Direction

All six anemometers at the two wind towers and one wind direction transmitting vane at the wind tower in the open were recorded on one 20-pen, 108 ohm resistance, 12 volt DC electromagnetically actuated, separate circuit, Esterline-Angus Operations Recorder, Model No. AW, with hand-wound, spring-driven, clock chart-drive. A chart speed of 3 inches per hour was found to provide adequate records of the wind velocities prevailing at the wind tower site.

The recording of 16 separate circuits placed a sufficiently heavy load on two automotive vehicle type lead-acid storage batteries to discharge them in about one week's time. Battery power demands in such service are usually large, because anemometers tend to stop on contact when lulls in the wind occur, thus subjecting the batteries to

continuing discharge for long periods. In order to protect against loss of records due to discharged batteries, and also to reduce the task of maintenance of charge by frequent replacement of discharged batteries with a set fully charged at Fraser, Colorado, about 7 miles away, the simple DC recorder circuits were modified through the addition of capacitor and resistor components.

The introduction of capacitors and resistors modified the length of the effective electrical impulse reaching the 108 ohm-resistance pen-actuating electromagnets. Steady rate discharge of batteries in anemometer circuits, such as would occur when the spindle should stop on closed contacts, would then take place through a 4,700 ohm resistance, rather than through the 108 ohm electromagnets; but, for each cycle of opening and closing of contacts, the discharge from the 2000 microfarad (muf) capacitor would produce a surge of electrical energy sufficient to actuate the pen and produce a clear record.

A different modification was necessary to reduce battery power requirements of the wind direction recording circuits. A 135° included-angle cam on the wind vane shaft can close either one or two contacts at one time, thus making it possible to record wind direction from eight 45° sectors. With simple wiring, one or two circuits are closed at all times, thus causing continuing discharge through one or two recorder electromagnets. The wind vane circuit was modified through the introduction of a gas voltage regulator tube, a capacitor, and a high resistance.

The 90-volt battery is active only in charging the capacitor. When a charge has built up in the capacitor exceeding the breakdown potential of the gas voltage regulator tube, ionization of the gas momentarily converts the voltage regulator tube into a conductor, and permits the capacitor to discharge. In doing so the sensitive relay closes, momentarily energizing the 12-volt pen-electromagnet circuits. The closing of wind direction circuits by the cam on the wind vane merely serves to distribute the impulse to the proper recording elements. The cycle is repeated about once every 108 seconds.

The wind direction and velocity circuit modifications, made by C. R. Daum, Electronics Engineer, Office of the Chief Engineer, Research and Geology Branch, Bureau of Reclamation, Denver, Colorado, were based upon circuits by Dr. L. J. Anderson of the Navy Electronics Laboratory (3). Figures 38, 39, and 40 show the assemblies and wiring diagrams of the panel board as installed in the wind recorder shelter. Figure 41 shows wind direction and velocity recorder chart traces as produced by simple and modified circuits. It will be noted on the chart, that before modification of the circuits, the wind velocity record of the "mile" circuit consists of 8 short "pips" and two long "pips" for each ten impulses. The long "pips" are caused by the bridged contact actuating points, visible in Figure 37.

These long "pips" served to simplify chart transcription at higher velocities, and also served as a check upon the completeness of record of the other 8 points.

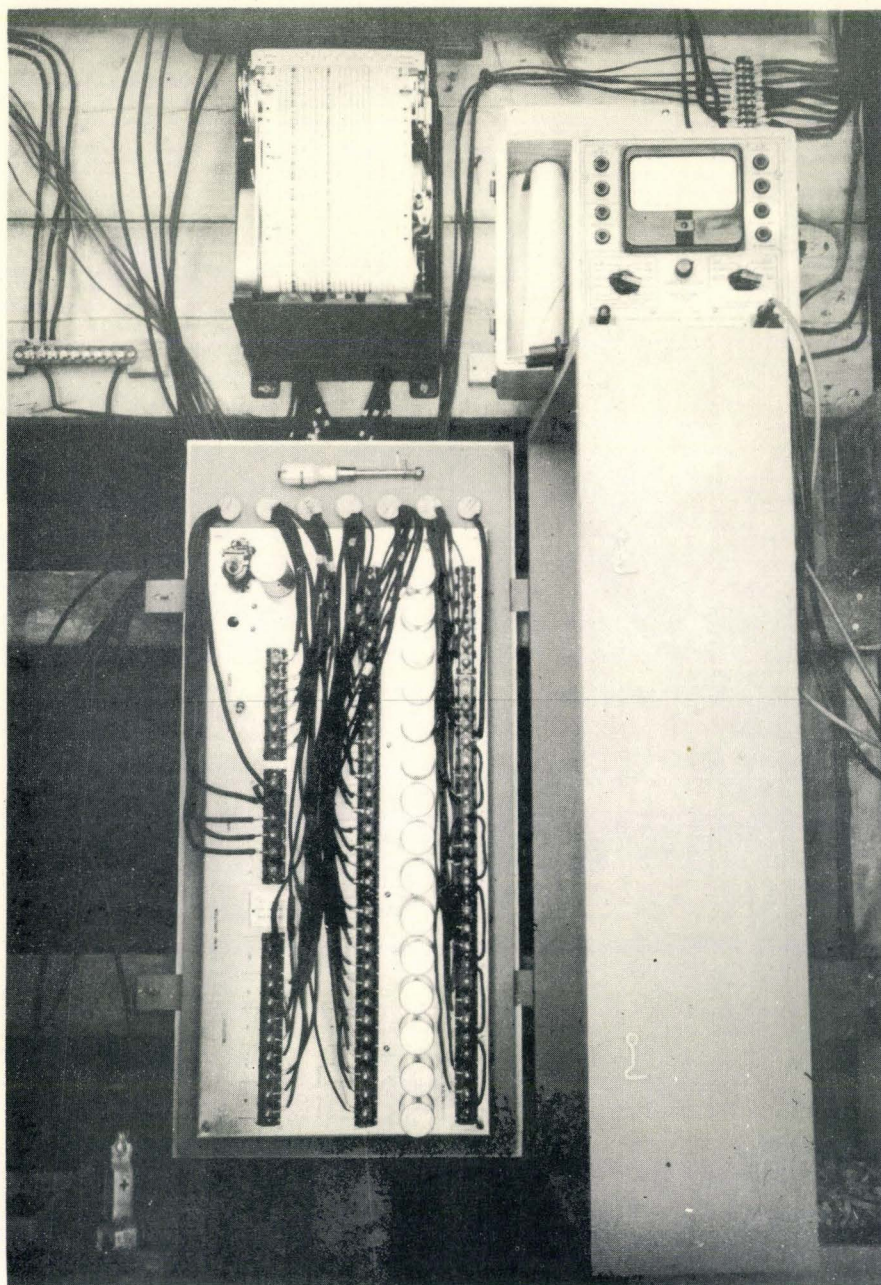


FIGURE 38. Wind direction and velocity recording instruments at wind towers. Instrument in top center is a 20-pen Esterline-Angus operations recorder. Circuit tester is shown in upper right corner. Panel in center is capacitor-resistor assembly which is detailed in Figures 39 and 40. Storage and dry-cell batteries can be seen in lower left corner. June 1, 1950.

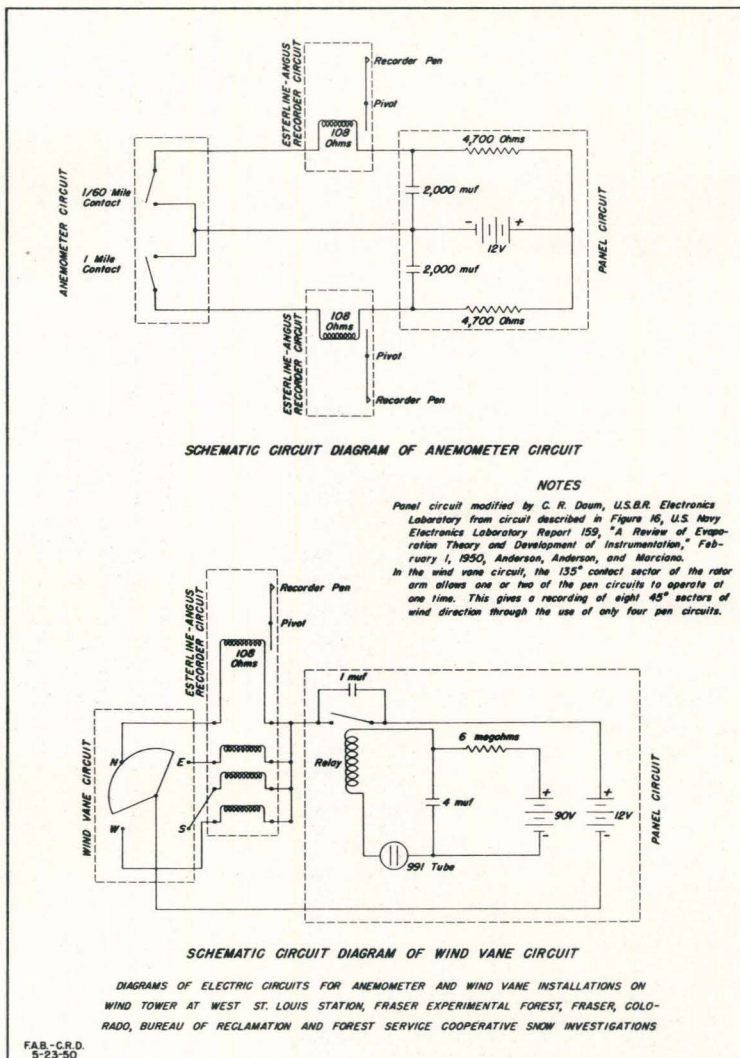


FIGURE 39. Schematic diagram of anemometer and wind vane circuits.

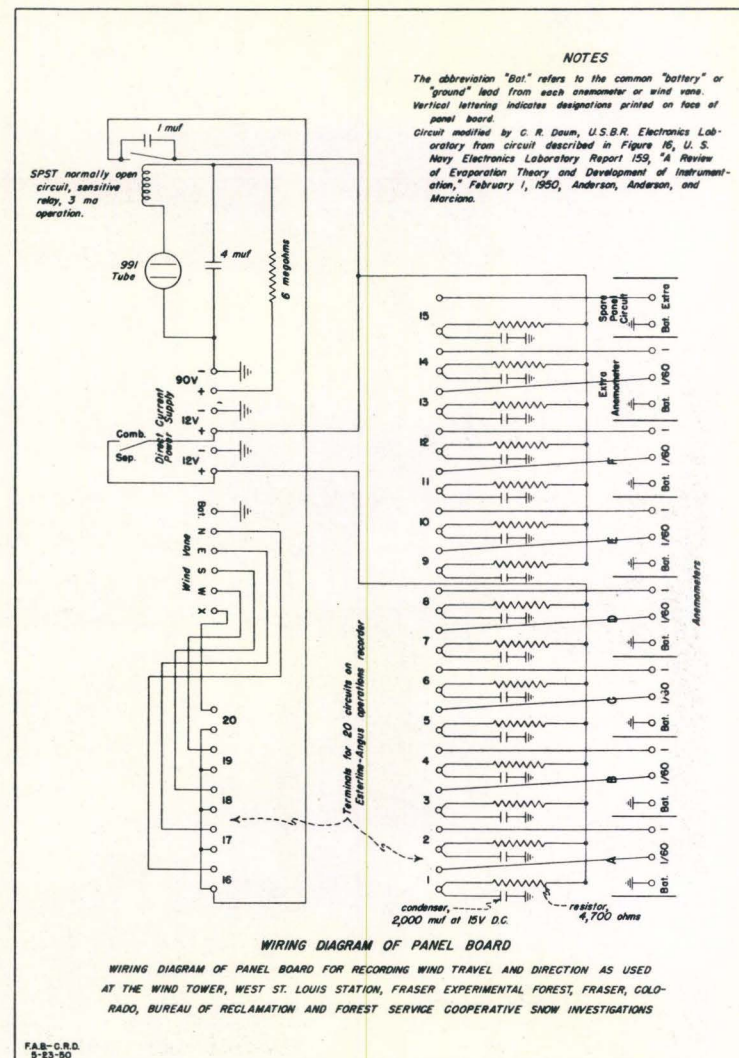


FIGURE 40. Wiring diagram of panel board.

The record produced by the modified circuits does not reproduce the long "pip", due to the inherent characteristics of the capacitor-discharge circuit. It was necessary, therefore, to make frequent checks of the completeness of the record. This was attained chiefly through comparison of the chart-recorded totals with the odometer increments, and, at times, by comparing the one mile and 1/60 mile records from the same anemometer.

The operations recorder has a spring-driven, escapement-controlled chart feed. As it is very difficult, under field conditions, to adjust a clock to feed the chart exactly at the required number of inches per hour, it is usually necessary to make a time correction before records are transcribed from the chart. Correct time entries, inserted at frequent intervals on the margin of the chart, served as reference points for time corrections.

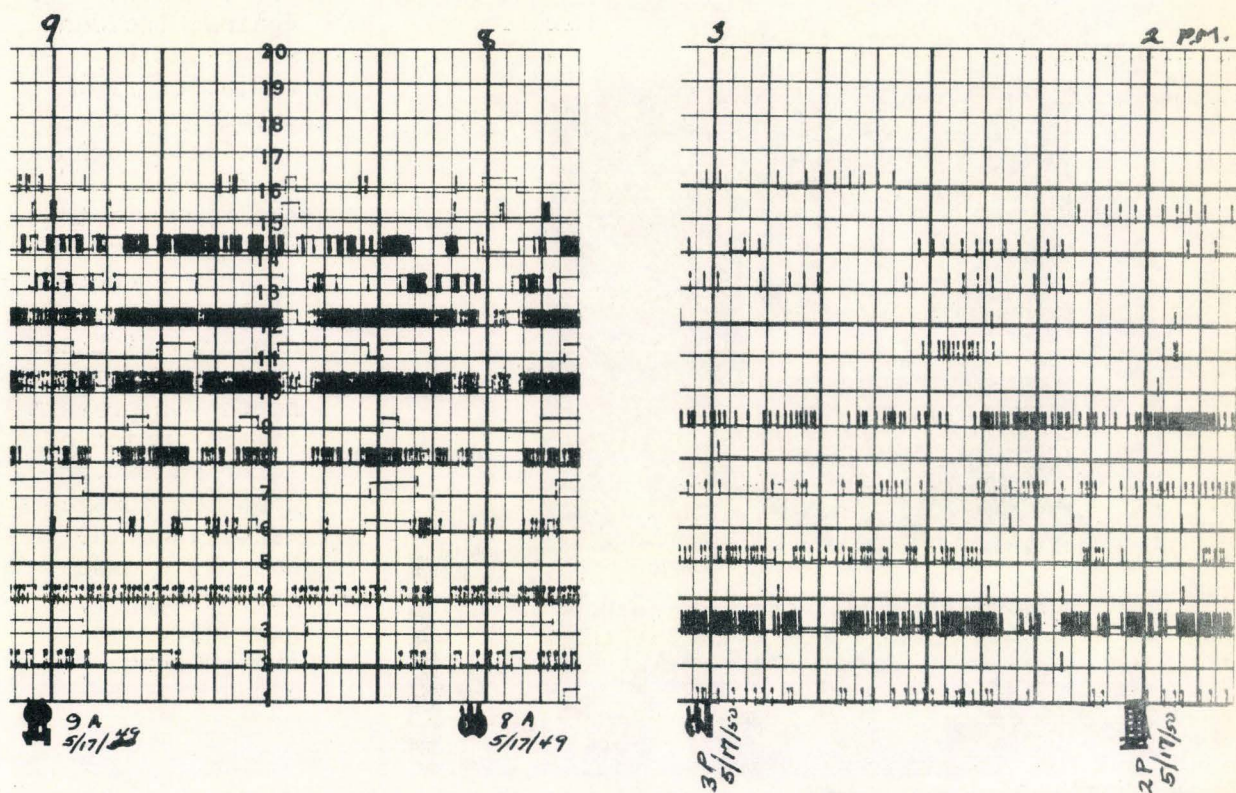


FIGURE 41. Records of wind travel and direction before and after modification of the circuits, March 1951.

4. Temperature and Humidity Measurements.

a. The Weather Instrument Shelter

The instrument shelter used for the exposure of temperature and relative humidity measuring instruments is the standard large Weather Bureau shed-roof type, shown in Figure 42. This shelter is sufficiently large to house a hygrothermograph, maximum and minimum thermometers, and a crank-type psychrometer. The shelter protects instruments against incident solar and sky radiation from above by a freely ventilated double roof. The shelters are installed upon solidly anchored timber or log supports with the door facing the north, to prevent direct impact of solar radiation upon the instruments when the door is opened for reading or servicing the instruments.

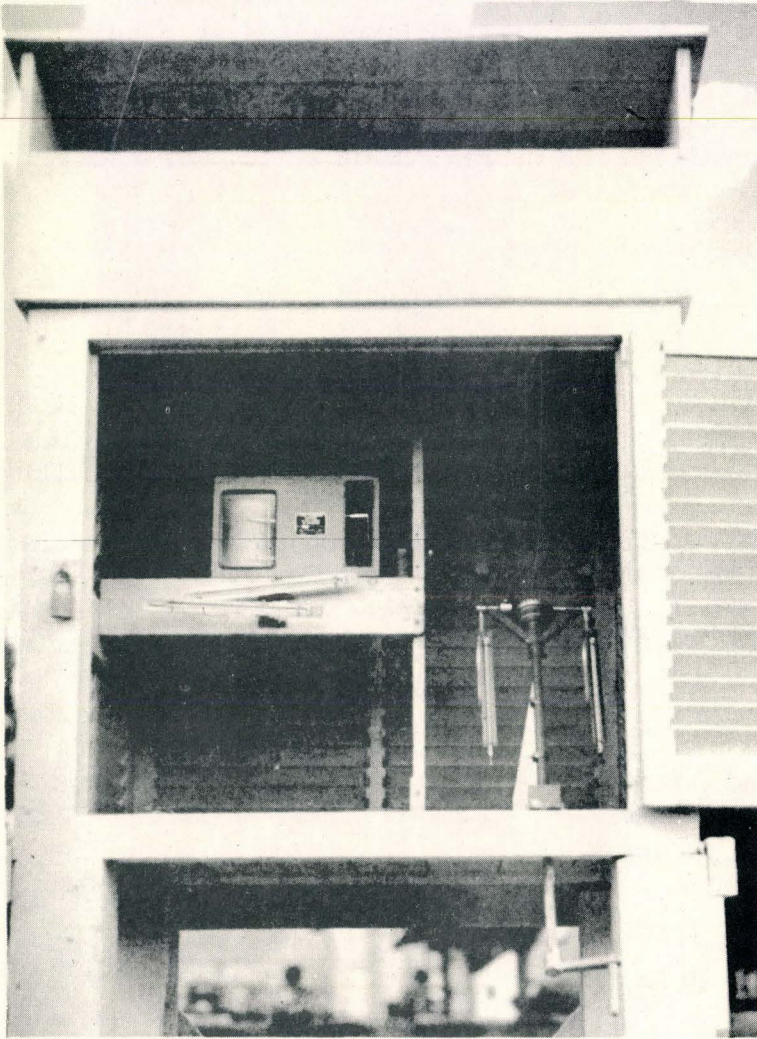


FIGURE 42. Interior of hygrothermograph shelter at Shadow Mountain Camp, June 8, 1948.

b. Thermometers

Standard Weather Bureau maximum and minimum thermometers were mounted on Townsend-type supports shown in Figure 42. This support is provided with clamps to hold the thermometers. The minimum thermometer

rests at the proper angle with reference to the horizontal to assist in the depression of the "rider" in the capillary tube upon falling temperatures, but to resist upward movement of the "rider" upon rising temperatures. Provision is made for rotation of the clamp to bring the "rider" to the temperature current at the time of servicing. The maximum thermometer clamp is free to rotate upon release of a positioning latch. Spinning of the maximum thermometer at the time of servicing exerts a centrifugal force which returns the mercury from the capillary tube into the bulb until the current temperature is reached.

c. Crank-type Psychrometer

A crank-type psychrometer was used. The instrument shown in Figure 42 was built in the shops of the Division of Design and Construction, Bureau of Reclamation, Denver, Colorado. It was patterned after the standard Weather Bureau design. This manner of rotating wet and dry bulb thermometers offers several advantages when used on snowmelt investigations:

- (1) It permits spinning the thermometers in the shade of the instrument shelter without exposure to direct sunlight.
- (2) The gear drive produces high velocities of motion through the air without the need of electrical power supply such as is needed for motor-driven air aspirators.
- (3) This psychrometer makes it possible to spin easily the thermometers for the long periods of time required to attain the true depression of the wet bulb at air temperatures below 32°F.

The thermometers used in the crank-type psychrometers were matched sets which conformed to Weather Bureau standards for psychrometric pairs. The wet-bulb cloth socks were replaced with new ones as soon as they became visibly stained. Distilled water was used to wet the socks at the time of a psychrometric reading.

d. Hygrothermograph

Continuous records of air temperature and of relative humidity are obtained by hygrothermographs. Instruments designated as Model No. 594 by the Friez Instrument Division, Bendix Aviation Corporation were used. Figure 43 shows the sensing elements and the leverage systems used in this model instrument.

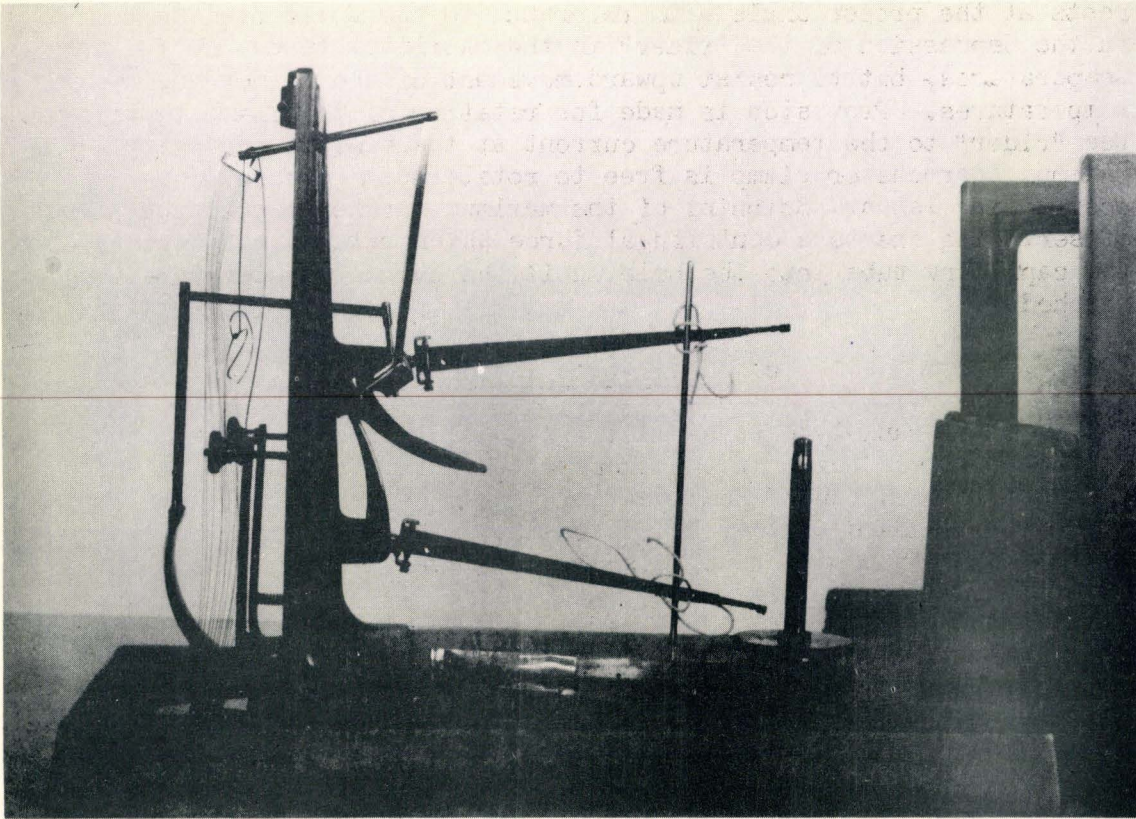


FIGURE 43. Hygrothermograph tied for shipment.

e. Temperature Recording System

The temperature element is a liquid-filled Bourdon tube, one end of which is attached to a hinged arm which permits adjustment of pen position and changes of the temperature indicating range. The movement of the pen spans a range of greater than 100°F . The temperature recording system is accurate within one degree Fahrenheit within the entire range of 100°F . The hinged support permits selection of temperature indication designations on the chart to include seasonal ranges. The lever system contains provision for adjustment of lever-arm motions to translate the movement of the Bourdon tube into movement of the pen to conform to the printed chart scale. As the temperature recording system is mechanically actuated, before a record of a change in temperature is produced, a sufficiently large change in the volume of the liquid in the Bourdon tube must take place to exert forces large enough to overcome the resistance to change of shape of the Bourdon element, pivot friction in the lever system, and pen drag on the chart. It is evident, therefore, that the temperature recorder is relatively insensitive to small and rapid fluctuation of air temperature and that exact agreement is seldom attained between the chart-recorded and thermometer-indicated maxima and minima. Adjustments to the lever-arm ratio, if necessary, can be made only with the aid of

accurately controlled temperature chambers. Changes in pen position on the chart are made simply by repositioning the hinged arm holding the Bourdon tube, through repositioning of the milled nut on the hinge anchor bolt.

f. Humidity Recording System

The measurement and recording of the water vapor of air over a snowfield is extremely difficult. The water vapor content of the air is usually derived indirectly from measurements of dew point or of relative humidity. Probably the most satisfactory method now available is the dew point recorder method, recent improvements of which are described by Barrett and Herndon (5). However, this method was not considered applicable to the field installations of the Cooperative Snow Investigations because of the delicacy of its component parts, its demands for electrical energy and refrigerants, and because of its high cost. Instead, the human-hair type of hygrograph was adopted for this program because of its relative simplicity and lower cost. The relative humidity recording system of the hygrothermograph consists of a hair sensing element, a lever system (including rocker arms), and the pen, all of which are shown in Figure 43.

The hair element consists of twelve clusters of about 4 human hairs each, affixed in banjo-string fashion to brass clamping plates. The use of human hair is based upon its characteristic of changing length in response to changes of relative humidity of the air over a considerable range of air temperatures and water vapor pressures. Only hairs in a natural condition possess this characteristic. Hair that has been modified by the application of heat or subjected to chemical changes loses sensitivity and responsiveness to change in relative humidity of the air. Hair suitable for use in hygrographs is treated with ethyl ether for one hour to extract fats. The presence of fats or oils on hair elements is very undesirable. The changes in length of human hair in response to relative humidity changes are practically logarithmic between relative humidities of 20 and 100 percent. The rocker arms in the lever system serve to convert this exponential response to linear movement of the pen. Detailed discussions of the human-hair hygrometers are given by Middleton (18) and Mueller (23).

It has been observed that different hair elements change their lengths different amounts in response to identical relative humidity changes. This necessitates adjustment of the lever arm ratios to change the degree of magnification of the lever system to retain a standardized pen travel on printed recorder charts. It was found that the recorder lever system is very sensitive to changes in the main lever arm ratios. Figure 44 shows, on the right, the simple set screw provided for clamping the main lever arm. Great difficulty was experienced in clamping the lever arm as the cupshaped end of the set screws tended to deform the surface of the main lever arm to a crater into which the set screw would clamp. Accordingly, the main lever arm was improved by the incorporation of a micrometric adjustment, as shown on Figures 44 and 45.

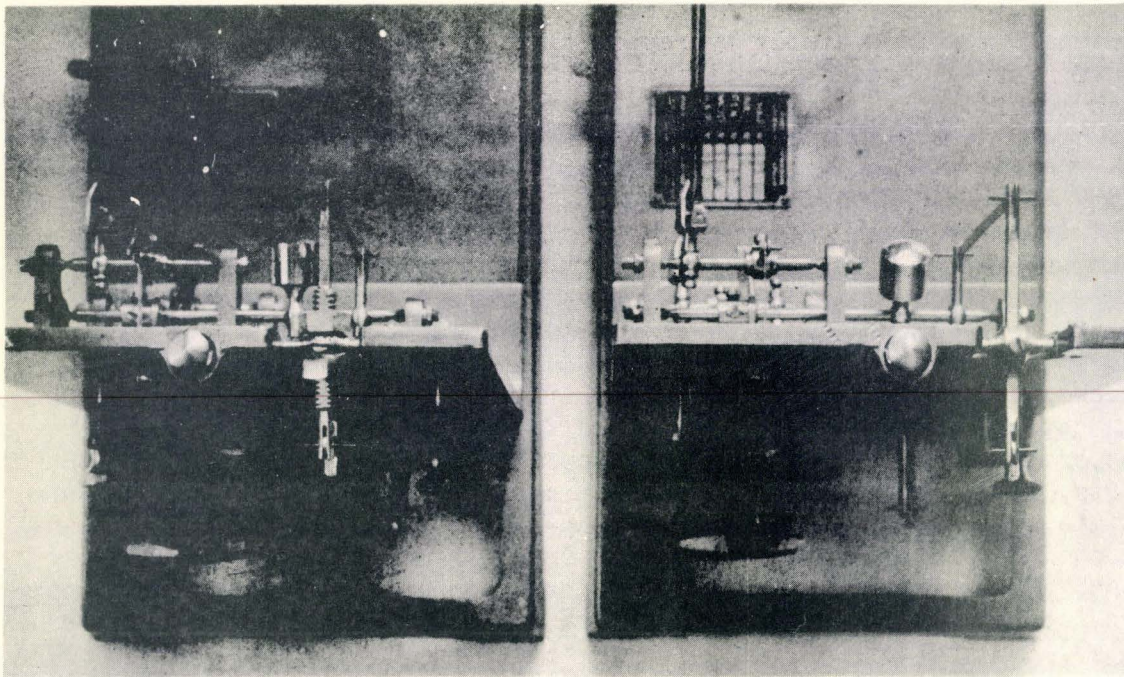


FIGURE 44. Two hygrothermographs showing old and new adjustable lever arms, October 4, 1950.

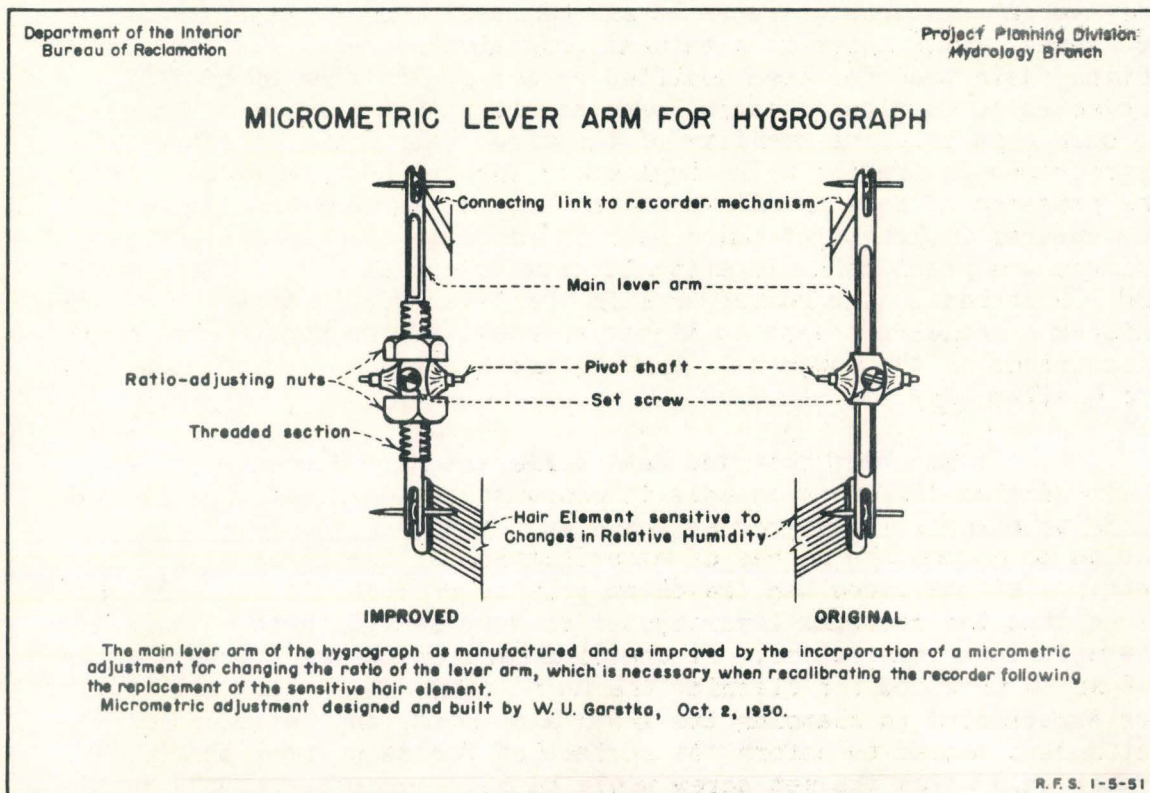


FIGURE 45. Micrometric lever arm for hygrograph.

A change in the position of the fulcrum of the main lever arm of 1/20 inch changed, for a difference of 45 percent relative humidity, the chart span of the pen from 45 to 39 percent. This means that a change in the position of the fulcrum of 1/120 inch changes the total span (0 to 100 percent) of the pen travel on the chart by 2 percent indicated relative humidity. The use of the micrometric lever arm adjustment made it possible to return exactly to a previously tested position of the fulcrum.

It was observed in a number of instruments that excessive time lags were evident in the charts. In certain instances this was found to be caused by too close a mounting of the rocker arm contact-retaining spring, so that, at certain positions of the rocker arms, the spring would rub against the arm and impede movements of the pen arm. This difficulty was removed by cutting new spring retainer grooves in the pins on the rocker arms, as shown in Figure 46.

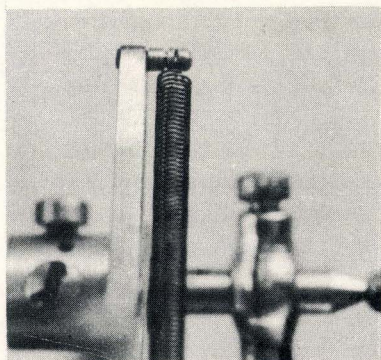


Figure 46. Lower rocker arm and pen shaft of hygro-thermograph showing repositioned tension spring attachment, October 4, 1950.

Another source of trouble may be due to inaccurate positioning of the rocker arms with reference to each other, as a result either of inaccurate attachment to the shafts or to misalignment of the shafts. The rocker arms should be positioned so that their contact is along the crests of the curved surfaces. Inaccurate positioning of the lever-system components may cause loss of part of the record when the end of the lower rocker arm contacts the vertical chassis. This can be corrected by proper clamping of the various levers to the shafts in regard to the angular travel which each lever must perform, so that rocker arms contact each other near the center of their arcs when the pen rests at 50 percent relative humidity on the chart.

g. Sensitivity of the Humidity Element

The human-hair humidity element is relatively insensitive to rapid fluctuations in relative humidity. This slow responsiveness is further damped by the pivot friction and pen drag of the recording mechanism. Before a record is produced of a change in relative humidity a sufficient change must result in the amount of water adsorbed on the hair to produce enough change in length of the element to exert enough force to overwhelm pivot friction and pen drag, and move the pen. Inherent accuracy of the human-hair hygrometer is generally accepted as ± 3 percent relative humidity and sensitivity of ± 1 percent relative humidity in the range between 20 and 95 percent relative humidity at air temperatures above freezing. At lower temperatures, possible freezing of the adsorbed water on some hairs may cause abrupt

changes in lengths not indicative of changes in relative humidity. At temperatures considerably below freezing, when water vapor pressures become very low, the hair element's response tends to be more and more completely dominated by temperature changes alone. Also the hairs respond very slowly at low temperatures, the lag becoming almost infinite at -40°C . According to Middleton (18) the change in length of human hair is about $1/15$ as much per degree C as is the mean change in length for a change of 1 percent relative humidity.

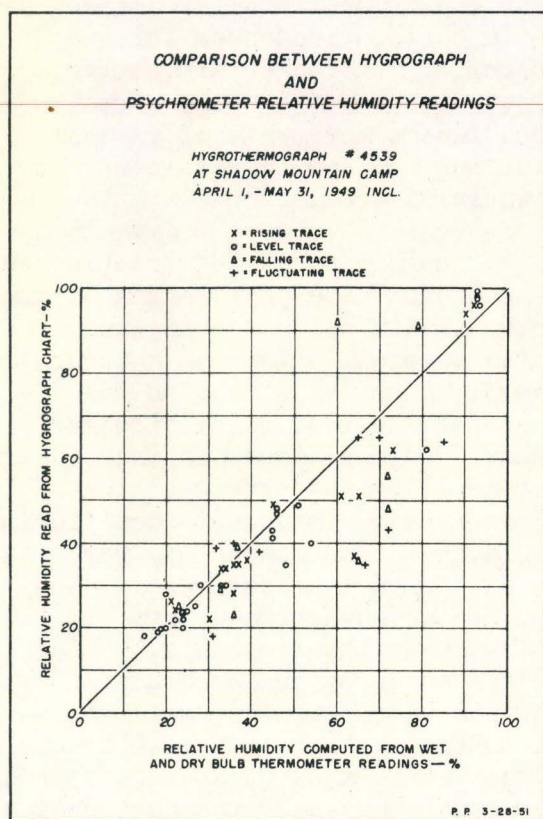


FIGURE 47. Comparison between hygrograph and psychrometer relative humidity readings.

It is evident, therefore, that the recorded relative humidity can only rarely indicate the true relative humidity at the instant of observation. For this reason, exact accord between relative humidity recorded on the chart and relative humidity determined by the wet and dry bulb psychrometer is seldom observed. As this lag is operative upon both increasing and decreasing relative humidities, the hygrograph produces a record which acceptably reflects the changes in relative humidity which occurred over the period recorded. Discrepancies as large as 30 percent may be noted between chart-recorded and psychrometer-measured concurrent relative humidity for a hygrothermograph in the best possible adjustment. A comparison between such readings for the Shadow Mountain Station is shown in Figure 47. It is evident that the hair element of a hygrograph cannot be calibrated with reference to a few psychrometric determinations performed in the field.

h. Calibration

The hygrothermographs used in the Cooperative Snow Investigations were calibrated in the controlled temperature and relative-humidity rooms of the Concrete Laboratories of the Research and Geology Branch, Office of the Chief Engineer, Bureau of Reclamation, Denver Federal Center, Denver, Colorado. Controlled temperature chambers maintained at temperatures varying from -30°F to $+220^{\circ}\text{F}$ are available.

Two chambers were used for humidity element calibration:

1. 73.4°F--50-percent relative humidity
2. 73.4°F--100-percent relative humidity (fog room).

The humidity in the 73.4°F 50-percent relative humidity room is controlled through the use of the Dunmore sensing element(13).

The Dunmore humidity sensing element responds instantly to microchanges in relative humidity and transmits these changes to the indicator in terms of electrical current. It consists of a polystyrene cylinder, a dual winding of precious-metal wire, a coating of moisture-sensitive compound, and plug-in contact pins. Since the coating is highly sensitive to moisture, a microchange in relative humidity changes the amount of moisture held in the coating and changes the conductivity between the two wires, thus changing the amount of current indicated on the dial of the meter. The temperature and humidity controls used are manufactured by the American Instrument Company, Silver Springs, Maryland, as described in their Bulletin 2164 (2). The installation is capable of maintaining relative humidity within ± 1.5 percent, with a sensitivity of 0.5 percent.

Fog conditions are maintained in the 73.4°F 100-percent relative humidity fog room through a continuous spraying of water from specially designed nozzles. Hair elements were calibrated in these two chambers and no attempt was made in the field to adjust the relative humidity pens to agree with wet and dry bulb psychrometric measurements. It was found that replacement of the hair elements required readjustment of the main lever arm ratio, which could be performed only in the controlled-temperature and relative-humidity chambers.

As facilities such as those in the Bureau of Reclamation's Concrete Laboratories are unique, humidity element calibration in the field may be done in small sealed chambers within which known relative humidities can be produced through the exposure of trays of saturated aqueous solutions of certain salts. For example, sodium chloride, NaCl, at 40°C produces in the closed chamber a relative humidity of 74.7 percent. Detailed information on this subject is given by Carr (9) and Stokes (25).

1. Suggestions for Operating Hygrothermographs

Experience and observations made during the conduct of these cooperative investigations suggest the following precautions and operational instructions:

(1) Exposure.--A hygrothermograph should be installed in a shelter that allows free ventilation, but at the same time restricts the entry of blowing snow. It should be mounted on a shelf, and off the floor of the shelter, to allow air circulation all around the hygrothermograph. The shelter should also shade the instrument from solar and sky radiation, and have a ventilated roof to prevent the interior of the shelter from heating up due to the solar heat absorbed

by the roof. The Weather Bureau large instrument shelters are considered standard, although even they will fill up with blown snow in windy exposures. The small so-called "Cotton Region" shelters, which were designed for use of maximum and minimum thermometers, are not desirable for the exposure of hygrothermographs.

(2) Care in handling.--Because of the sensitivity and delicacy of the sensing elements in the hygrothermograph, the instruments should be handled with extreme care. No jars or strains should be transmitted to either the Bourdon tube or to the hair element. The hairs should not be touched, because oils from the hand will change their responsiveness and the slightest snag may stretch the hairs.

(3) Preparation for shipping.--Before transporting the hygrothermograph long distances, the following precautions should be taken. The hairs should be slackened by looping a fine wire through the slit in the lever arm and twisting it around the adjusting nut, thus holding the hairs in a loose position as shown in Figure 43. When thus tied down, no vibration or tension can be placed on the hair element in shipment. The main lever arm should be pulled down far enough to put the hairs into a definite slack, but not so far as to cause the other end of the lever arm to contact the hinged cover. Both hygrograph pen and thermograph pen should be tied loosely to the upright pen releasing arm to prevent vibration, but not to prevent normal movement of the thermograph pen in response to changes in temperature in shipment. The hold-down clip used to retain the charts on the clock drum should be taped to the inside floor of the instrument to prevent loss or bending. The clock should be removed and wrapped separately to exclude dust.

(4) Inking and cleaning pens.--The cork to the ink bottle supplied for use with the thermograph has a flat bladed ink dipper which is used to add ink to pens. Periodically, the pens should be cleaned by pulling this blade through the pen point between the nibs. Periodic washing in 99 percent ethyl alcohol may be required, when instruments are operated under dusty conditions.

(5) Partiming of pens.--It is important when using the hygrothermograph records for computation of dew points that the two pens register on the same time line of the chart at any one instant. The pens are fastened to the pen arms with sliding friction grips and can be slid on the pen arms until the two pens agree. Normally, this is done when the instrument is calibrated, but in addition, the partiming should be checked periodically. When sliding the pen on the pen arms, the pen arm should be held firmly to the upright pen releasing arm so that no strain will be put on the sensing elements. The humidity pen arm should first be lowered slightly to relieve tension in the hairs.

(6) Putting chart on drum.--The charts used were Chart No. 207-WB (Summer range) Friez Part No. 502495 and Chart No. 209-WB (Winter range) Friez Part No. 502495-1.

These charts have a 7/8-inch tab at each end of the chart grid. The tab at the left end has the identifying number and the tab at the right end has space for pertinent remarks, instrument number, station, and date. Before wrapping chart around the drum, the tab with the notes is folded under. The chart is wrapped on the drum so that the folded end is lapped over the unfolded end and the fold is just past the slot in the flange at the bottom of the drum. The chart clip is inserted within the folded end and its end is engaged in the slot in the flange. The clock then rotates so that the pen will ride up on the paper over the chart clip without catching. If the wrong end of the chart is folded under, the pen point will catch on the fold around the chart clip and the clock movement may either pull the pens off the pen arms or the pens may stop the drum. Care should be taken to see that the chart rests squarely against the bottom flange. The chart can be snugged up on the drum by rubbing with the hands to slide the unfolded tab under the chart clip. Care should be taken that the horizontal lines on the chart match where the two ends meet. This can be checked by sighting along one of the lines across the joint.

(7) Starting clock.--Because of the slack in the clock gears the starting time of the pen trace will not agree with the printed grid unless the slack is taken up in the proper direction. To take up the slack, the clock is rotated counter-clockwise until gears are tight before setting pen on time line. When released the clock may rotate slightly clockwise and then remain stationary until moving gears have again taken up the slack.

(8) Changing temperature range.--The summer charts have a temperature range from 10°F to 110°F and the winter charts range from -30°F to 70°F. The range can be set to span lower temperatures, provided that proper notation of the effective range is entered on each chart. Changing from one range chart to another is done when the temperature is fairly constant. The chart reading of the pen trace is observed on the old chart before removing it. The new chart is put on and the pen moved to proper reading by turning the adjusting screw at the end of the case near the Bourdon tube. Turning the screw to the right will lower the pen and vice versa. The new setting should be checked with a thermometer.

(9) Time checks.--As often as is practical, time checks should be made on the hygrothermograph charts. The time can be noted on the trace by a small "pip" of the pen. To make this "pip" depress the pen arm very slightly with the end of a pencil. Just the weight of the pencil is usually sufficient to depress the pen enough to make a visible "pip".

(10) Notes.--Adequate notes should be kept on the chart. Time of starting and ending and any intermediate time checks should be included. Temperature and psychrometer checks should be noted when read. All notes can be written on the chart in the field. When writing on the chart, first note the correct time and then remove

the clock from the instrument. Make notes on the chart while it is still on the clock drum. The clock should be replaced to the proper time setting.

The importance of careful operation and maintenance of properly calibrated hygrothermographs is brought out in Section D, "Analysis of Rates of Snowmelt."

5. Precipitation Measurements.

a. Sacramento-type Storage Gages



FIGURE 48. Two Sacramento-type snow storage gages at Upper West St. Louis Site, April 1949.

The Sacramento-type storage gages used are similar to those described by Codd (10), are 100-inch and 200-inch capacity, and were fabricated in the Bureau of Reclamation shops from Weather Bureau plans. The gage is in the shape of a truncated cone with an 8-inch diameter opening at the top. These are mounted on supports above the level of the maximum accumulation of snow as shown in Figure 48. Wind shields of the Alter type were fastened to the gages to control air currents which might deflect falling snow away from the opening. As illustrated in the photograph, Figure 48, the wind shield consists of a circle of slats hung from a circular frame around the opening. The bottoms of the slats are restrained loosely by a chain so that they are free to move slightly in the wind and dislodge any accumulated snow.

(1) Antifreeze solution.--At the start of the snow season, the gages are charged with a concentrated antifreeze solution. Amount of charge used is about 1 to 1-1/2 times as much as the accumulation of precipitation to be expected in one season. Instructions given by the Weather Bureau (27) were followed when preparing the antifreeze charges. This reference recommends using a 29.6 percent solution of calcium

chloride for the charge. This charge has a freezing point of -59.8°F . Higher concentrations are not recommended, as they will result in the formation of solid hydrates of calcium chloride, with consequent rise in the freezing point temperature. As the charge is diluted by the precipitation its freezing point rises. When diluted with a volume of water equal to the full initial charge, the freezing point is 16.5°F . Instructions for mixing the charging solution are given in the Weather Bureau Manual referred to above. To prevent evaporation, a small amount of light motor oil (SAE 10) is added. This forms an oil film on the surface which reduces any evaporation. Since the calcium chloride brine is very corrosive, the interior of the gage was coated with asphalt. The exterior of the gage was painted flat black to increase absorption of solar heat.

(2) Calibration.--The gages are measured by reading the depth of fluid with a stick which is lowered into the gage from the top. These depths were converted to volume by reference to calibration curves. These curves were derived for each gage by adding known increments of water to the initial charge of brine, and getting the corresponding depth readings.

(3) Method of operation.--On or about October 1 of each year the gages were charged with a known weight of calcium chloride solution and oil. Stick readings were taken and the charging volume calculated from the calibration curve. On April 1, next, stick readings were again taken and the total volume computed. The difference of these two volumes was the increment of precipitation that was caught by the gage during the winter. Readings were taken again on May 1, June 1, and about October 1. At this last date the gage was drained into measuring pails and the solution was weighed as a check on the stick readings.

b. Intensity Gages

The recording precipitation gages used are Friez Universal Recording Rain and Snow Gages, one of which is shown in Figure 24. They operate on the principle of weight transmitted through a series of linkages to record precipitation directly on a chart in inches depth. Precipitation is received in a bucket through an 8-inch diameter opening. The chart is held on a clock-driven drum which rotates once each week. The resulting record gives for each storm, the depth of precipitation and the time and intensity at which it fell. The gages have capacity for 12 inches of precipitation.

c. 8-inch Storage Gage Cans

The 8-inch storage gage cans used are similar to the Weather Bureau standard 8-inch precipitation gages. During the snowmelt season they were charged with a calcium chloride and oil solution. Readings were made weekly by weighing the can and contents as shown in Figure 49. Increments in weight between weekly weighings were converted to inches of precipitation by using the conversion factor for 8-inch cans:



FIGURE 49. Weighing an eight-inch precipitation gage at West St. Louis Station, April 1950.

large circular dial. The diameter of the snow core is such that its weight in ounces is equivalent to inches of water. To prevent stick-



FIGURE 50. Weighing a snow tube and core of snow.

1 pound water = 0.55 inch depth. The cans at the Headquarters and West St. Louis Stations were equipped with the Alter-type wind shields while the cans in the Fool Creek and East St. Louis Creek areas were unshielded.

6. Snow Measurements.

Snow surveys are performed with the Federal Snow Sampler, which is described by Marr (21, pp. 9-14). Essentially, the sampler is a core-cutting duralumin tube. The cutting end is fitted with a 1.485-inch inside diameter case-hardened steel cutter. Water equivalent of the snow sample is determined by weighing with a spring scale with

ing of snow cores in the sampler, and freezing of snow to the outside of the tube, all surfaces are kept polished by frequent applications of a high carnauba content paste automobile finish wax, in accordance with recent practices developed by snow surveyors. Figure 50 shows a pair of snow surveyors weighing the tube and core of snow.

7. Stream Flow Measurements.

a. St. Louis Creek Gaging Station

Location of the St. Louis Creek Gaging Station is shown on the frontispiece and is described as follows in Water Supply Paper 1119, (15):



FIGURE 51. Rating section with cableway on St. Louis Creek, June 1, 1950.

"St. Louis Creek near Fraser, Colorado, Location.—Waterstage recorder, lat. $39^{\circ}54'45''$, long. $105^{\circ}52'35''$, in sec. 34, T. 1 S., R. 76 W., a third of a mile downstream from confluence of East and West Branches, and $4\text{--}1/4$ miles southwest of Fraser. Drainage area.—32.8 square miles."

Records are available beginning with August 1934. Extremes, including water year 1949, are: Maximum 353 cfs, June 15, 1935, from rating curve extended above 220 cfs; minimum 3.2 cfs, April 9, 1935. The Geological Survey evaluates the records as "good" except for periods of ice effects or of no gage height record, which are "fair." There has been no regulation or diversion above the St. Louis Creek Gaging Station during the period of stream flow record.



FIGURE 52. Looking upstream toward St. Louis Creek Gaging Station, June 1, 1950.



FIGURE 53. Looking downstream toward St. Louis Creek Gaging Station, June 1, 1950.

Views of the St. Louis Creek Gaging Station together with the rating section, are shown in Figures 51, 52, and 53. Stream gage heights are recorded by a Stevens Model A-35 recorder. Data are secured in the winter during the months of October-April inclusive with the aid of a 15-inch depth of oil in a 14-inch diameter cylinder within the gage house well.

b. Fool Creek Gaging Station

The Fool Creek Gaging Station is designed to handle year-round stream flow in a region where winter temperatures of -30°F are not uncommon. Included in the design of the station are the following elements: (a) rock and masonry cut-off walls; (b) broad-crested weirs; (c) San Dimas flume; (d) stillwell; and (e) built-in ground-water well. The station has a range in measuring capacity of from 0.08 to 60.0 cubic feet per second from a drainage area of 1.11 square miles. Spring and summer flows are measured through flume and weirs while winter flows have been measured by means of a special orifice plate, inserted as a bulkhead in the downstream section of the flume. A ground-water well, constructed as an integral unit of the station, furnishes information on ground-water fluctuations in the valley-fill material adjacent to the weir section. Details of the gaging station are shown in Figures 54, 55, and 56.

Functions of the essential elements in the gaging station are as follows:

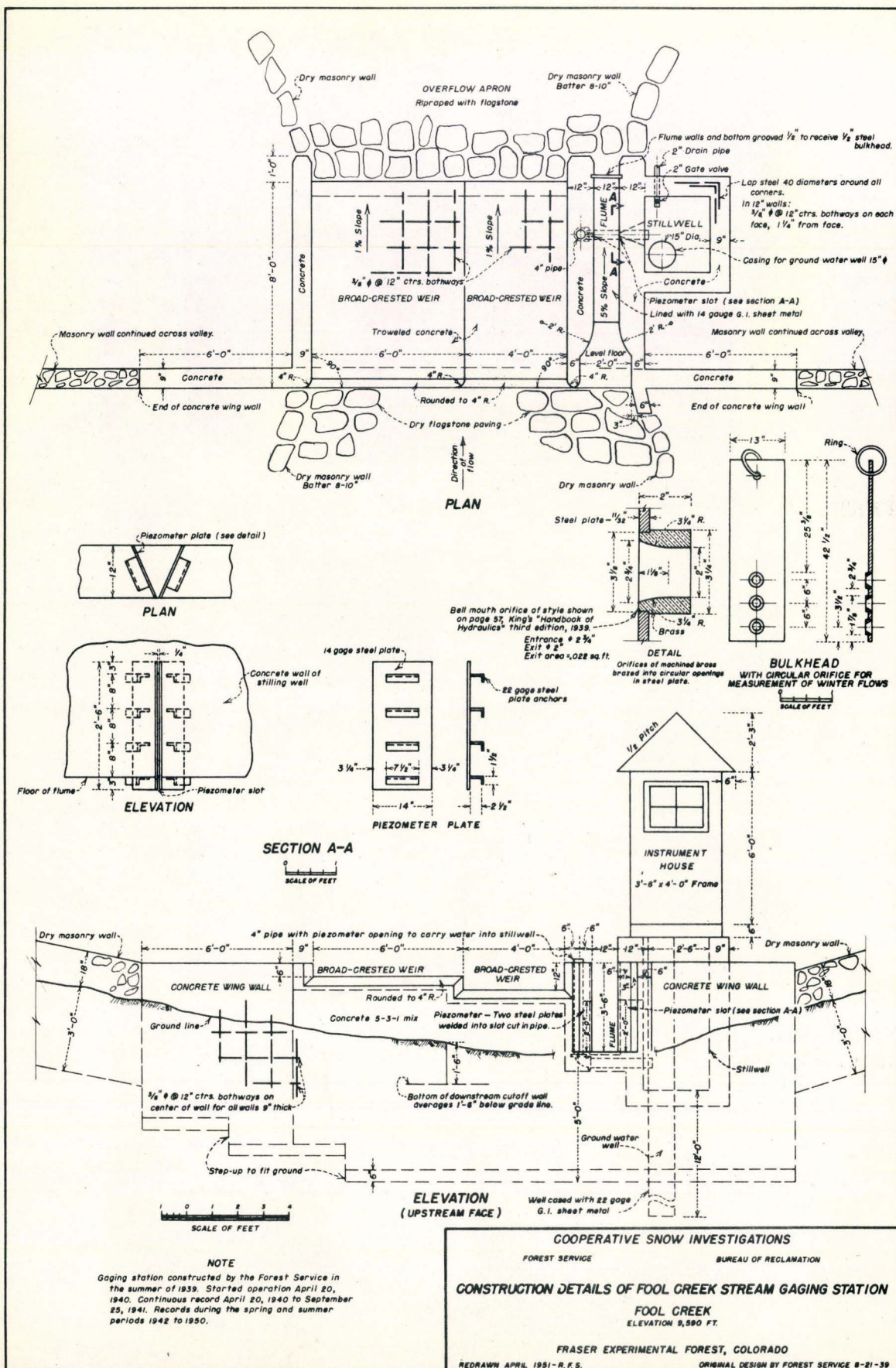


FIGURE 54. Looking downstream toward Fool Creek Gaging Station.



FIGURE 55. Looking upstream toward Fool Creek Gaging Station, August 1, 1950.

- (1) The masonry wall across the valley bottom prevents the stream from meandering away from the gaging section, insures the diversion of all surface flow through the section, and reduces subsurface flow to a practical minimum.
- (2) The pair of 9-inch wing walls that flank the gaging section serve the dual purpose of anchoring the gaging section and of forcing subsurface flow to the surface where it can be measured by flume and weirs.



- (3) The 4- and 6-foot broad-crested weir sections measure maximum spring flows.
- (4) The 1-foot-wide San Dimas flume measures normal summer flows.
- (5) The orifice plate measures minimum winter flows.
- (6) The stillwell measures the depth of water in the flume and weirs.
- (7) The ground-water well measures fluctuations of ground water in the valley-fill material adjacent to the gaging section.

When excavating for the footings and walls of the gaging station, it was found that the valley fill was very gravelly and porous. Because subsurface flow through this porous material appeared to be of significant volume, ground-water flow beneath the masonry wall is determined by taking supplemental ground-water stage and velocity measurements along this wall.

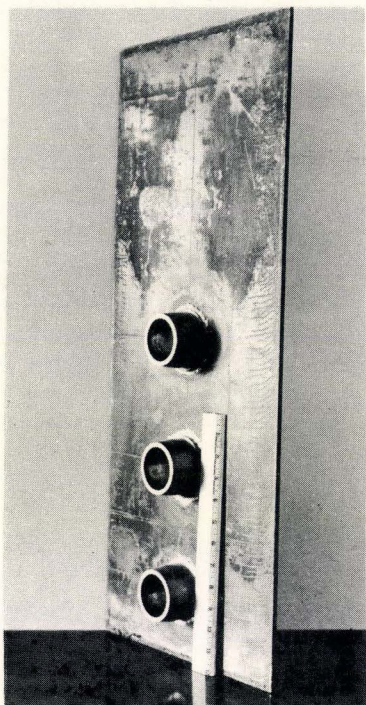


FIGURE 57. Orifice plate with three 2-inch bell-mouthed orifices.

The design for the station as constructed provides for continuous, yearlong measurement of flow rates. For measurement of the normal range in flow, a 1-foot San Dimas flume is set in the stream channel. This flume is 3 feet deep and 6 feet long below the end of the cylindrical entrance transition. Pressures are measured at the longitudinal midpoint of the flume. At the left side and 2-1/2 feet above the floor of the flume was constructed a broad-crested weir 4 feet wide, with a top slope of 1 percent downstream. In combination with the flume, this weir is expected to handle all flows but the possible maximum flood. To provide for stream flow of extreme magnitude, a second broad-crested weir is included above the first; this one is 6 feet wide. Just above the downstream end of the 1-foot flume, slots are built into the structure to accommodate an orifice plate for measurement of low autumn and winter flow. This plate contains three bell-mouth orifices, each 2 inches in throat diameter and is shown in Figure 57. In late summer, when water depths in the flume drop to about 0.12-0.15 feet and no large flow peaks from rain may be expected, the orifice plate is installed in the flume.

A Stevens Type K recorder installed in the recorder house, measures pressure head transmitted from the 1-foot flume and broad-crested weirs to the stilling well. Charts are changed once a week.



FIGURE 58. Fool Creek Gaging Station prepared for winter.



FIGURE 59. Fool Creek Gaging Station in spring before removing winter's accumulation of snow.

During the winter of 1940-41 a continuous record of winter flow was kept by using the orifice plate. A gasoline lantern was kept burning in the stilling well to prevent freezing and consequent errors in measurement of water stage. Winter flow through Fool Creek Gaging Station averaged 0.160 cfs. This winter record demonstrated that flow during this season was constant base flow and subsequent winter records were considered unnecessary. It has been observed that the flow is very uniform during the winter season. Flow does not appear to fluctuate perceptibly from year to year. It has been necessary, however, to provide some protection from excessive icing in the flume and consequent difficulties of opening in the spring. Before the first snow in the autumn the whole flume is covered with a timber deck provided for the purpose and the whole structure is then banked over with sawdust or earth as shown in Figure 58. The piezometer slots are sealed watertight, the stilling well drained, and the recorder and float removed for the winter period. The appearance of the gage the next spring just before clearing away the snow is shown in Figure 59.

Flume ratings have been made under actual field operating conditions. Rating data are taken whenever possible for both the flume and broad-crested weirs. This is done by means of a velocity-head rod (28) and (30) with depths and velocities measured at four points across the flume, and at eight points across the lower broad-crested weir. Since flow over the broad-crested weir is relatively rare, special care is taken to include any exceptional summer storm or other period of unusually high flow. Stilling-well depths are recorded to correspond to all velocity-head data for both flume and weir.

Ground water wells

The three ground water wells in the Fool Creek basin are located at regular intervals across the valley bottom about six feet upstream from the masonry cut-off wall. Each well has been boarded over and provision made to measure height of water level. One well on the west side of the stream has been equipped with a Friez Type FW-1 recorder for continuous measurement of ground-water fluctuations. Water level readings are made weekly from the time the wells thaw out in spring to late autumn.

c. East St. Louis Creek Stream Gage

The stream gaging station on East St. Louis Creek is at an elevation of about 10,000 feet. Subsurface flow is held to a minimum by locating the station in a narrow portion of the valley. The control is a trapezoidal broad-crested weir with a rectangular flume notched into the center. The station is operated from the beginning of spring melt until late in the fall when only base flow remains. No attempt has been made to measure winter flow or subsurface flow. A Friez Type FW-1 recorder is used to measure the pressure head transmitted from the weir to the stilling well.

8. Transportation. The vehicle shown in Figure 60 used for transportation over deep snow is a surplus U. S. Army M-7 snow tractor transferred from the Corps of Engineers-Weather Bureau Cooperative Snow Investigations. The tractor is a two-passenger vehicle with rear tracks and front skis. At the advice of Mr. Forrest L. Rhodes, Program Director of the Corps of Engineers-Weather Bureau



FIGURE 60. M-7 snow tractor as modified for use at Fraser Experimental Forest, April 29, 1950.

Cooperative Snow Investigations, several modifications were made to the tractor. The steering column was modified by strengthening the U-bolt fastening the lower end of the column to the frame. Outriggers were mounted on each side of the cab to form platforms for carrying luggage, shovels, and other equipment, and a ski rack was fastened to a pipe frame built up over the canvas top. Since these vehicles and parts are no longer produced, it was necessary to "cannibalize" parts from one extra vehicle to keep the other operating.

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Bureau of Reclamation

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Forest Service

For the Forest Service, Dr. W. G. McGinnies, Director, Rocky Mountain Forest and Range Experiment Station, has general supervision over the cooperative program. Dr. H. G. Wilm, Silviculturist, was responsible for technical aspects of the program until January 1948, at which time he was succeeded by Dr. L. Dudley Love, Division Chief, Forest Influences. Mr. Bertram C. Goodell, Forester, was in immediate charge of installation and operation of field instrumentations within the Fraser Experimental Forest. Mr. E. G. Dunford, Forester, assisted in the investigations and preparation of this progress report.

Other Agencies

The St. Louis Creek Stream Gaging Station is operated and maintained by the Geological Survey, United States Department of the Interior, under cooperative agreement with the Colorado State Engineer. The Fraser, Colorado, standard precipitation gage is operated by the Weather Bureau, United States Department of Commerce.

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